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THE PHILIPS 100 kV ELECTRON MICROSCOPE

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There is hardly any other instrument receiving so much attention as that paid to the electron microscope by almost everyone practising the natural sciences: the physicist — creator of the science of electron-optics upon which this instrument is based — sees in the development of the analogy with the optical microscope a fine exemplification of the conception of the wave character of the material particles; the biologist, the analyst, the medical practitioner, the metallurgist and many others will be glad to have the use of this instrument; the engineer, finally, experiences in its practical execution an accumulation of heterogeneous technical problems which are (or may we say were?) a challenge to his ingenuity.

Fundamentals of the development

The step from optical microscopy to electron microscopy has brought mankind a great deal farther in the knowledge of the ultra-minute: in the extreme case the beam of light can only make objects of the order of about 0.2 micron (2000 ångström) distinguishable, whereas the electron beam has already made objects of 10 to 20 ångström visible, thereby permitting us to penetrate deeply into the fine structure of technically applied materials, into the world of bacteria and viruses, even into the field of large molecules, with but a relatively short and maybe not unbridgeable gap separating us from the individual atoms (of the order of 1 ångström).

Notwithstanding the successes already attained, electron-microscopy may be said to be still in its infancy. This is symptomized in the fact that the instrument with which one works still demands a great deal of the observer's attention, it being rather more an art than a science to make really good pictures with the electron microscope, pictures in which the very utmost is reached as regards resolving power, contrast, etc.

Defining briefly the fundamental idea of the electron microscope developed by Philips in recent years and now brought into production, we may say that the foremost aim in the construction of this instrument has been to facilitate work with the electron microscope as far as possible. The perfecting of the auxiliary apparatus and making it automatic, the systematic elimination of sources of possible errors, far-reaching simplification of all the manipulations necessary for operating the instrument, afford the investigator, on the one hand, the possibility of producing very good micrographs as routine work in a fraction of the time that was required to get a picture with former instruments, whilst on the other hand, if precautions are taken which require more time and skill, the acme of perfection can be reached.

The development of the Philips electron microscope has been based upon the fundamental work carried out by Le Poole and his co-workers in the Institute for Electron-microscopy at Delft. An experimental microscope, which was the result of that work, was described in this journal three years ago [1]).

Construction of the instrument

The instrument comprises four main parts:
1) the microscope tube, with, among others, the

[1]) J. B. Le Poole, A new electron microscope with continuously variable magnification, Philips Techn. Rev. 9, 33-45, 1947.

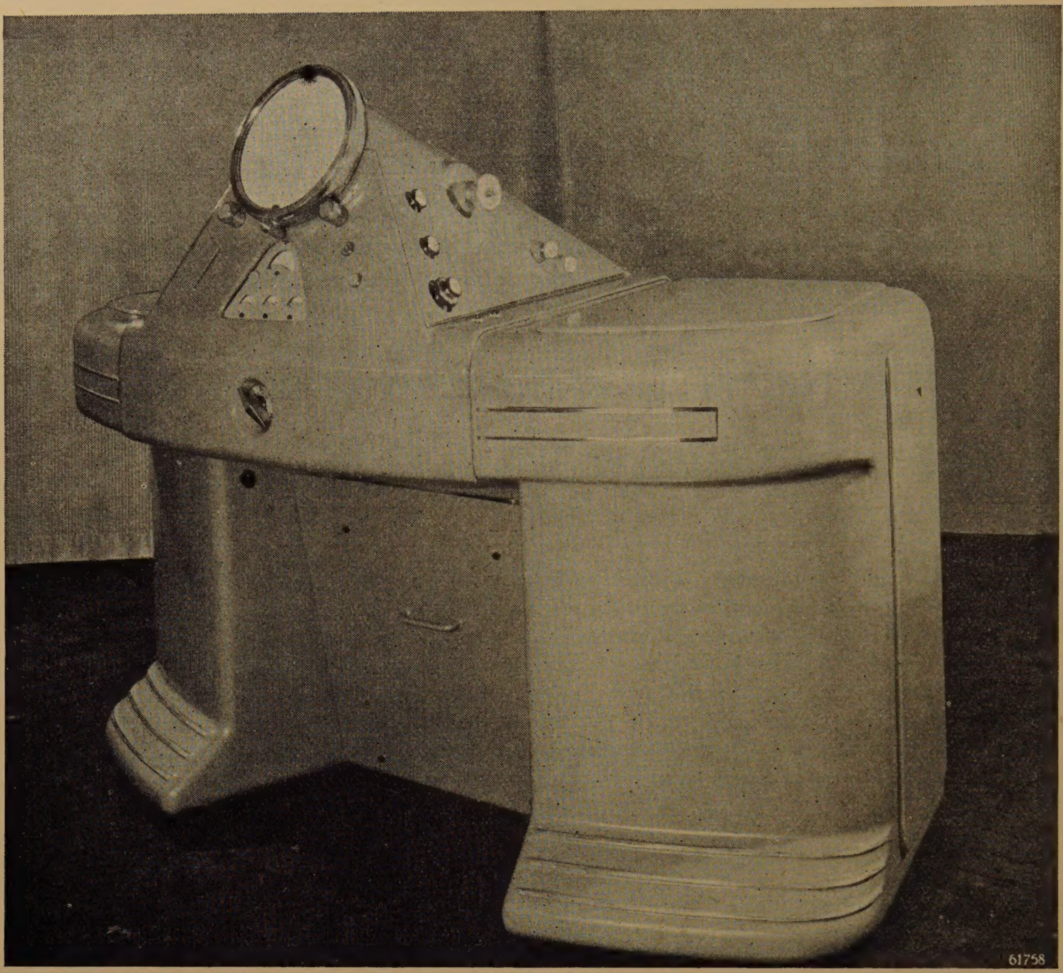

Fig. 1. The Philips 100 kV electron microscope (type number 11980). The microscope tube is mounted on a desk at an angle. The desk, comprising three compartments of cast aluminium, contains in the left-hand compartment the pumping system, in the right-hand compartment the supply apparatus for the lenses and all the other electronic apparatus, and in the middle, underneath the microscope tube, the high-tension generator, whilst on the panel underneath the circular viewing screen and on either side of the tube are various control knobs, control meters, etc.

electron source, the electron lenses — which are of the magnetic type —, the specimen holder, the viewing screen and the device for photographing;

2) a system of pumps for evacuating the microscope tube;
3) a high-tension generator supplying the voltage for accelerating the electrons;
4) the apparatus for energizing the electron lenses.

These parts, together with the necessary electrical gear, are built into a kind of desk shown in the photograph in *fig. 1* and in sectional view in *fig. 2*. The microscope tube is mounted at an angle on the desk with the uppermost end closed with a flat glass plate (16 mm thick in order to withstand the air pressure of 1 atmosphere when the tube is evacuated). On the inside of this glass plate is a fluorescent screen 20 cm in diameter, on which the enlarged image of the object is produced so that it can be observed through the glass.

In the following description of the various components most time will be devoted to the microscope tube itself, but also the principles of construction applied in the auxiliary apparatus deserve some attention. In conclusion details in the operation of the instrument will be passed in review, not in order to give directions for use but rather to show in how far the object outlined above has been attained.

The microscope tube

Principles of the electron-optical system

The formation of the image with an electron-optical system, in particular with magnetic electron lenses, has been discussed at length in the aforementioned article in this journal [1]), so that here

it suffices to recall the most important points.

A beam of electrons, emitted from a filament and accelerated in a strong electric field, is directed upon the specimen to be investigated. Different parts of the specimen attenuate the beam to a varying extent by scattering the electrons more or less. Thus the beam passing through it carries with it an image of the structure of the specimen, and after its subsequent passage through the field of an electron lens the plane of the specimen (object plane) is produced on a greatly magnified scale onto another plane (the image plane) situated farther along. The image can be made visible with a fluorescent screen in the image plane, but it can also first be magnified still further by a second and possibly still more electron lenses. The most commonly employed is the construction with two lenses (two-stage microscope), the first of which is called the objective lens and the second the projector lens.

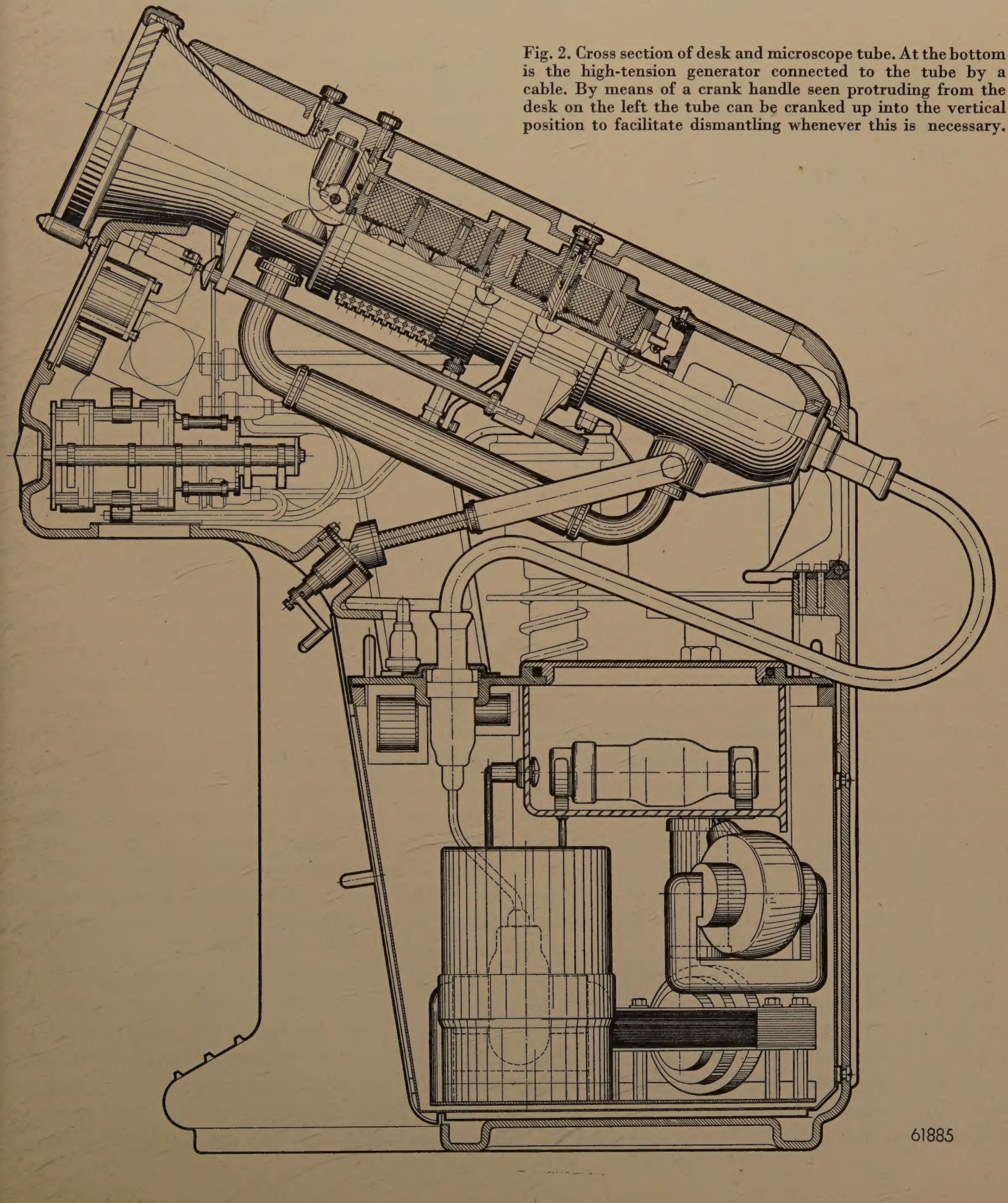

Fig. 2. Cross section of desk and microscope tube. At the bottom is the high-tension generator connected to the tube by a cable. By means of a crank handle seen protruding from the desk on the left the tube can be cranked up into the vertical position to facilitate dismantling whenever this is necessary.

A magnetic electron lens is formed by the inhomogeneous magnetic field in a short coil. For a strong lens (small focal length) strong fields are required, for instance of the order of 0.6 Wb/m^2 (6000 gauss). These are obtained by giving the coil a large number of ampere-turns and completely surrounding it by an iron jacket, except for an annular gap in the inner wall. To concentrate the field still more an annular pole piece of a suitable profile is inserted in the opening of the coil on either side of the gap; see *fig. 3*.

In this way focal lengths of 3 to 4 mm are obtained with a lens of reasonable dimensions and a magnification of the order of 100 times can be obtained. The focal length of the lens can be varied by varying the excitation.

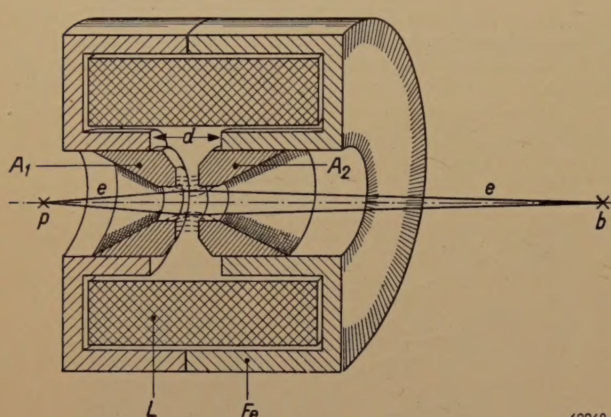

Fig. 3. Magnetic electron lens. L coil; Fe iron jacket with annular gap d; A_1, A_2 pole pieces; e electron beam. An image of an object at p is formed at b. Naturally the electrons have to travel in vacuum. To keep the space that has to be evacuated as small as possible, the annular gap is sealed vacuum-tight by filling it up with a non-magnetic material. — In actual fact the electrons do not travel along paths as drawn here: in the magnetic field they are moreover given a circling movement perpendicular to the axis, resulting in a helical orbit being followed. This is of importance when considering possible aberrations, but there is no need to consider it here; for this reason no account is taken of the circling movement, neither in this nor in the other illustrations.

The electron-optical system of the Philips electron microscope is mainly composed along the same lines as that of the experimental instrument designed by Le Poole. This system comprises not two but five magnetic lenses. The first of these acts as a condensing lens for "illuminating" the specimen, the second one is the objective lens and the last one the projector lens. The third and fourth lenses, which are energized alternatively, are denoted as the diffraction lens and the intermediate lens.

The intermediate lens makes it possible to reach a strong total magnification (in our case 60,000 ×) without the magnification of each of the three active lenses individually having to be excessively large; the main advantage is that the microscope is kept comparatively short (the overall length of the microscope tube is 81 cm). Moreover, by varying the excitation of the intermediate lens the magnification can be varied continuously within wide limits (from 4000 times to 60,000 times) with the whole area of the screen, which is 20 cm in diameter, still being completely covered. With a two-stage microscope it is hardly possible to get such a continuous variation of the magnification, as is explained at length in the article [1]) previously quoted.

By switching on the diffraction lens — a weak lens with wide bore — the enlargement is made smaller than that of the objective and projector together, and thus the range of enlargements from 1000 times to 4000 times is also covered, thereby linking up with the magnifications of the optical microscope. The diffraction lens derives its name from the fact that it affords a very simple means of obtaining an electron-diffraction diagram of the part of the specimen observed. This is achieved by adjusting the excitation of this lens in such a way that instead of the image plane of the objective lens its focal plane on the image side is displayed in the object plane of the projector lens (and thus onto the fluorescent screen). Just as in the case of the optical microscope, according to the theory already given by von Abbe, it is in this focal plane that the diffraction spectrum of the structure of the specimen appears. For the normal examination of a picture, in the path of the beam not far from the said focal plane, there is a very narrow diaphragm which allows only the first diffraction maxima belonging to the "coarse" structural details to pass through, which maxima have to contribute towards the formation of a well-contrasted image of these details. For obtaining diffractional patterns, however, it is the aim to obtain an image of the first diffraction maximum of each detail of the fine structure (arrangement of molecules and atoms). As these maxima lie much farther from the optical axis, the objective diaphragm just mentioned has to be replaced by a much wider one. Thanks to the presence of the diffraction lens, no other mechanical manipulations whatever are needed and it is therefore possible to change over in a few seconds from the normal image to the diffraction diagram of part of the specimen.

Fig. 4 gives a schematic representation of the paths followed by the electron rays in the three different situations: large magnifications, small magnifications and diffractional work. For the sake of clarity the width of the lens bores and of the electron beam is greatly exaggerated in these drawings: actually the path followed by the electrons

as far as the projector lens is nowhere more than about 1 mm from the axis, and it is not until they have passed through that lens that they diverge at large angles so as to cover the whole of the fluorescent screen.

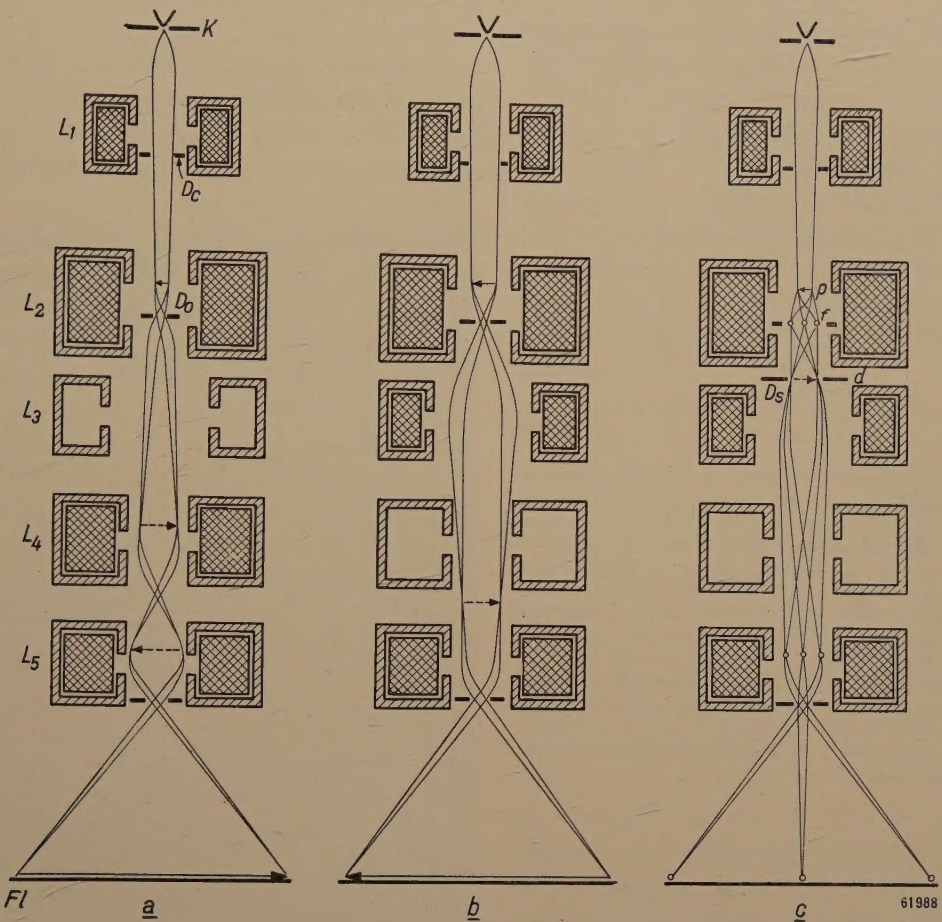

Fig. 4. Representation of the electron paths in the Philips electron microscope, which has five lenses: L_1 condenser, L_2 objective, L_3 diffraction lens, L_4 intermediate lens, L_5 projector; K the electron gun, F_1 fluorescent screen. The widths of the lens bores and of the electron beam have been drawn on a very much exaggerated scale for the sake of clarity. D_c, D_0 D_s are various diaphragms to be discussed later.
a) Situation with high magnification (4000-60,000 times); diffraction lens not energized.
b) With low magnification (1000-4000 times); intermediate lens not energized.
c) The situation for diffraction work. On the screen an image is produced of the focal plane f at the image side of the objective lens and not of the object plane p. An intermediate image of p is formed in the plane d.

nating current of 50 c/s, thereby causing the electron beam to "wobble", so that it still strikes the specimen in the same spot on the axis of the tube but at an angle varying in size and direction with a frequency of 50 c/s; see *fig. 5*. What this amounts to is that a single-plane beam is temporarily used with a much larger aperture than is usual (1/100th radian as against the normal 1/1000th radian). The blurring of the image caused by a small deviation between the specimen and the object plane of the objective lens is made much more pronounced by the larger aperture; when the excitation of the objective lens is varied in order to bring the object plane closer to the specimen the minimum of the blurring thus gives a distinct criterion for the coincidence of the object plane

In addition to the principle of the intermediate lens and the diffraction lens there are two other important developments used in our electron microscope which are due to Le Poole and which will be described here, namely the focusing device and the manner in which the image is photographed.

The focusing device consists, in our case, of two sets of deflection coils mounted between the condenser lens and the specimen. While observations are being made these coils are out of action, but for focusing they are energized by an alter-

with the specimen. Focusing with the "wobbling" beam is of particular advantage for the largest magnifications, when the images on the fluorescent screen have rather low luminosity.

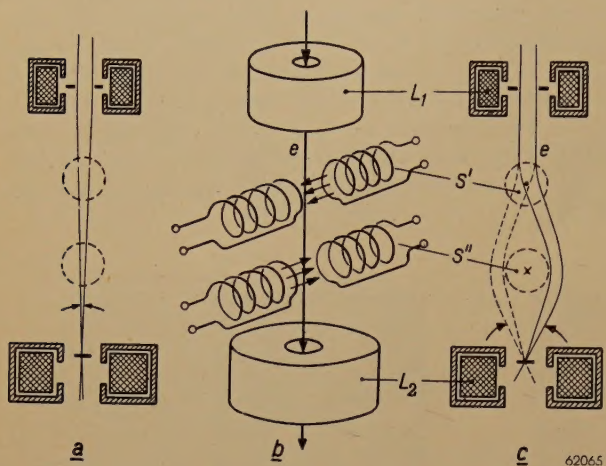

Fig. 5. Schematic representation of the focusing system. Between the condenser L_1 and the objective L_2 are two small coils S', S'', generating two magnetic fields in opposite directions and at right angles to the electron beam *e* (*b*). Normally these coils are not energized; the beam passes straight through and has a very small angle of incidence (*a*). Upon the coils being energized with a direct current the beam *e* is deflected by S' and brought back again by S'', in such a way that it strikes the specimen at the same point as before (*c*, the fully drawn lines). While focusing the coils are fed with an alternating current of 50 c/s; a "wobbling" beam is thus obtained (dotted lines in the drawing), which is equivalent to "illuminating" the specimen with a beam having a much larger angle of incidence than normal.

For photographing an image the electron beam is made to fall directly upon the photographic material. Following Le Poole's method, a roll-film is used which is placed between the screen and the projector lens, fairly close to the latter. The photographs thereby obtained are much smaller than the image on the screen, thus effecting a saving in the cost of the film and in the space occupied in archives, etc., whilst at the same time, owing to the greater concentration of the available electron energy, a relatively short exposure suffices. If necessary the photographs can subsequently be examined under a large optical magnification; thanks to the fine grain of the film nothing is lost of the resolving power of the electron microscope.

This method is made possible by the minuteness of the relative aperture at which the projector lens is used: the individual beams each producing an image point on the screen are so narrow that an astonishingly great depth of focus is obtained. The image is sharp from a few cm behind the centre of the projector lens right up to the screen and would in fact still be so at several metres beyond the screen.

The electron gun

The electrons are supplied by a V-shaped filament made of tungsten, surrounded by a metal cap with an opening of about 1 mm diameter through which the electrons can emerge; see *fig. 6.* This assembly is at a high negative potential (40 to 100 kV) with respect to the earthed metal shield of the microscope tube. The filament is fed by a transformer connected to the mains and insulated against 100 kV. The electrons emerging through the opening in the cathode cap are accelerated by the prevailing potential difference and, under the focusing action of the local electric field, follow in a narrow beam the axis of the tube.

The field required for focusing is obtained by giving a suitable shape to the cathode cap and the shield and keeping the cap at a negative potential of 80 to 100 V with respect to the filament. The latter is ensured by connecting the cap direct to the high-tension point a resistor being inserted between that point and the filament. At the same time this provides for a self-regulating action of the emitted electron

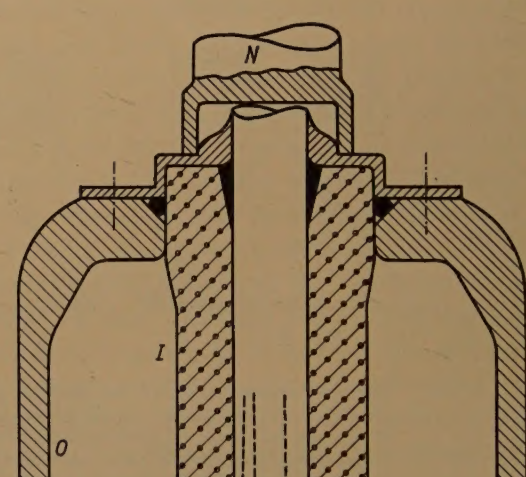

Fig. 6. Construction of the electron gun (simplified). *W* filament, *G* metal cap with small opening through which the electrons emerge. Filament and cap are carried by the cylindrical insulator *I* made of a special kind of "Philite", mounted vacuum-tight in the head of the earthed metal shield *O* of the microscope tube. *N* high-tension cable with rubber insulation and earthed shield, *a* entrance of the miscroscope tube proper.

current: as the emission current increases, the negative potential of the cap (acting as control grid) with respect to the filament increases, thus counteracting the increase of the current (according to the principle of a self-biased triode). We shall presently see that this regulating action is of great importance for the construction of the high-tension generator. The emission current with which one normally works is from 10 to 20 μA, of which only a very small fraction, say 10^{-10} A or still less, reaches the fluorescent screen at the other end of the microscope tube.

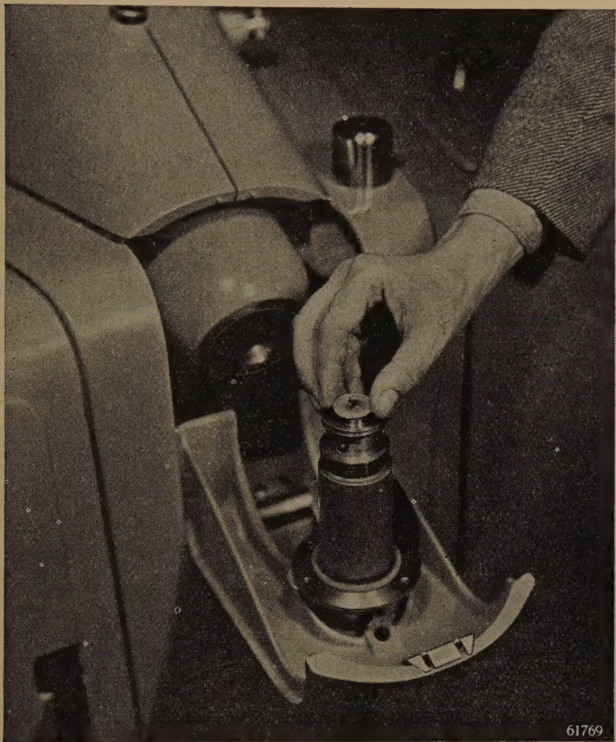

Fig. 7. Replacement of the filament. The removed cathode cap is seen standing on the desk above the man's hand.

Owing to the local relatively high temperature, when the electron microscope is in normal use, the filament has to be renewed every few days. This is very easily done, since the filament is mounted on a sintered glass base with fused-in plug pins which can easily be inserted in or taken out of the holder. The filament is reached by turning down a hinged cover protecting this end of the microscope tube, unscrewing the head of the shied and drawing the electron gun out (*fig.* 7). Each filament is previously centred on its base, so that after it has been properly plugged in the point of the V is automatically aligned in the opening of the cathode cap. If necessary, after the cap has been put back, the position of the point of the V can be corrected by slightly shifting the filament holder with the aid of three set screws.

The lenses, diaphragms and apertures

The electron beam originating from the electron gun enters the tube of the electron-optical system, first passing through the condenser. This relatively weak lens concentrates the beam more or less upon the specimen. The focal length can be adjusted between 30 and 2.5 cm. The angle of incidence of the electron beam striking the specimen varies between 0.002 and 0.00015 radian. A diaphragm in the condenser, 0.3 mm wide, limits the width of the beam. When the cathode end of the microscope tube is opened (fig. 7) this condenser diaphragm can easily be withdrawn from the condenser with a special tool, for cleaning it when necessary.

The next lens is the objective lens, a strong lens with a focal length of about 4.5 mm. In the conventional construction this lens has two pole pieces approaching each other to within 1 to 2 mm and having an axial bore of 1 to 3 mm through which the electron beam passes. In our microscope, however, the distance between the pole pieces and also the width of the bore is approximately 10 mm and the pole pieces have been made correspondingly heavier. The whole lens is "scaled up" as it were, as may be seen from *figs 8a* and *b*. This method of construction of the objective lens has three important advantages. In the first place the spherical aberration, one of the factors limiting the resolving power of the microscope, is appreciably reduced as compared with the normal construction. Secondly another important aberration, astigmatism, can be practically eliminated owing to the fact that the 1 cm bore can be mechanically worked with smaller relative deviations from the rotational symmetry

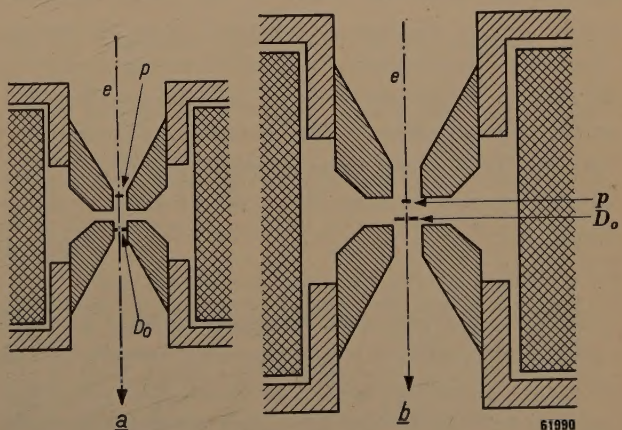

Fig. 8. *a*) The conventional construction of the objective lens. *b*) "scaled up" objective lens; *e* electron beam, *p* specimen, practically in the object side focus D_0 objective aperture.

than is possible with a bore of 1 to 2 mm, whilst magnetic inhomogeneities in the material of the pole pieces are almost entirely eliminated as a source of asymmetry thanks to the greater distance between the iron and the electron beam. Thirdly — and perhaps this is the most important advantage owing to the constructional consequences — the focal point of the object, which in the normal construction is always somewhere inside the bore of the upper pole piece, now lies in the space between the two pole pieces (fig. 8*b*). Thus the specimen, which has to be brought into a plane very close to the focal point of the object, can be brought into place by means of a straight rod from the side, whereas in the conventional construction a rather complicated mechanism was always needed to bring the specimen over the objective lens in the tube and then to lower it into position in the bore. Not only is the specimen holder thus made much simpler in our construction, but it is now also a practical possibility to make a very efficient "specimen lock", thereby reducing the time taken in exchanging the specimen and re-evacuating the microscope tube to only about 20 seconds. The construction of the specimen holder will be further described later [2]).

The objective aperture is likewise situated in the space between the pole pieces of the objective lens (fig. 8*b*). As already mentioned, two different apertures can be used, a small one for normal imaging (40μ) or a larger one for diffraction work (about 1 mm). Both apertures are contained in a platinum strip fixed to a rod-like holder which is also inserted from the side. It depends upon the depth to which the holder is screwed in, which of the two apertures is brought into the beam.

The position of the apertures can very easily be checked by switching on the diffraction lens of the microscope, when an image of the small aperture can be seen on the screen magnified about 200 times. Also any contamination of the diaphragm due to particles broken away from the specimen is immediately detected. Should the aperture need cleaning then the holder can be unscrewed and drawn out, without involving any dismantling of the microscope.

[2]) A "scaled-up" objective lens was already used by L. Marton (Phys. Rev. **58**, 57, 1940). From theoretical considerations W. Glaser (Z. Physik **117**, 285, 1941) has drawn the conclusion that in the normal construction of an objective lens the object plane can come to lie between the pole pieces when the lens is very strongly excited, and that the spherical aberration is then comparatively small. In the normal construction, however, the difficulty is encountered that with such a strong excitation the pole pieces become saturated. This does not occur in the "scaled up" construction with the excitation required here.

Contrary to the conventional construction, where the objective aperture is built in, inaccessible from the outside, and cannot be directly checked, with our microscope there need never be any uncertainty as to the condition and centering of the aperture, and as far as this is concerned one can always work under optimum conditions.

Between the objective lens and the next one, the diffraction lens, is a square selector diaphragm the size of which can be varied continuously. This is used for diffraction work, for selecting the part of the specimen of which it is desired to obtain a diffraction pattern. In the plane of this diaphragm an intermediate image of the specimen is then formed; upon the diaphragm being reduced the electron rays emerging from the outer parts of the specimen are prevented from taking part in the formation of the diffraction pattern. With the smallest opening of the diaphragm that can be used the effective plane of the specimen measures 1μ × 1μ and with the largest opening about 30μ × 30μ. The principle of the construction of the selector diaphragm is represented in *fig. 9*.

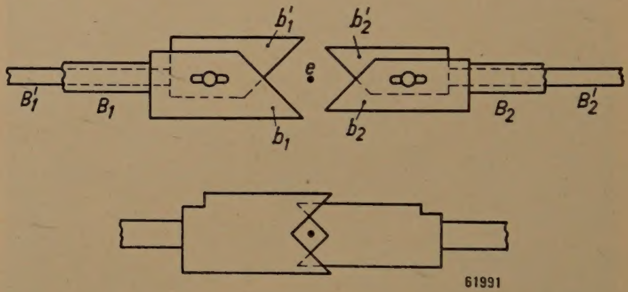

Fig. 9. Schematic representation of the construction of the selector diaphragm. e = axis of the microscope, perpendicular to the plane of drawing. Two fork-shaped pieces can be made to overlap more or less by means of the rods B_1, B_2. The square opening in between the forks is thereby varied continously in size and can be shifted in its entirety tothe right or left. The opening can also be displaced upward or downward (in the plane of drawing) by changing the position of one of the two wedge-shaped plates (b_1', b_2') of each fork with respect to the other (b_1, b_2) in the direction of the rods, by means of two other thin rods B_1', B_2' sliding in an axial bore of the first-mentioned rods. All four adjustments are made from the outside without disturbing the vacuum in the microscope tube; the adjustment is checked by projecting an image of the square on the fluorescent screen.

After passing the selector diaphragm the electron beam passes through the diffraction lens and the narrow bores of the intermediate and projector lenses. The functions of these various lenses have already been described in the foregoing, and their construction does not present any new aspects. All five lenses are provided with water-cooling for carrying off the heat generated in them by the excitation currents. To illustrate this

description a (somewhat simplified) cross-section of the whole of the microscope tube is given in *fig. 10.*

It is a problem of great practical importance how to ensure (*a*) that the electron beam passes freely through the numerous narrow openings and (*b*) that moreover the beam follows exactly the axis of each lens in order to avoid the aberrations inherent in rays oblique to the axis (coma, astigmatism). This latter point is of particular importance for the objective lens. The two requirements together imply in the first place that the axes of all five lenses must be accurately aligned. In our microscope this has been ensured in the following way. The condenser lens and the two halves of the objective lens — this has to be made in two halves to allow of the specimen table (dealt with later) being put into place — are joined together with precisely gauged fittings. The coils of the diffraction lens, intermediate lens and projector lens are wound on one common iron-core cylinder with magnetically insulating rings in between, the pole pieces for all three lenses, together with the necessary spacing rings, being inserted in the bore of the cylinder (fig. 10). In this way these last three lenses form one rigid unit, which in turn is connected to the first-mentioned part of the tube with a fitting, whilst the first pole piece of the diffraction lens, forming the link between the two parts of the tube, can be readjusted with set screws if necessary after the instrument has been assembled. The axes of the five lenses are thus so accurately aligned that any further adjustment on the part of the user of the microscope could not improve matters, so that there was no need to make any provision for this possibility. In the second place, however, it has now to be ensured that the electron beam entering the tube is directed precisely along the axis of the tube. Since the electron source has to be repeatedly renewed, it must be made possible for the user of the microscope to centre the beam anew when necessary.

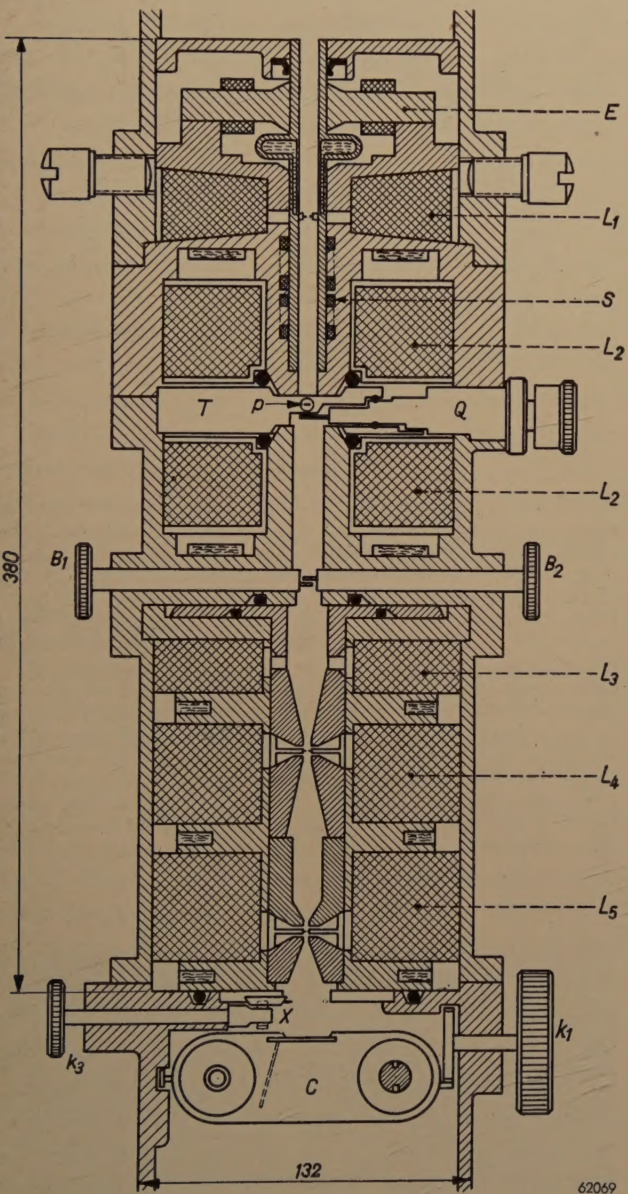

Fig. 10. Cross-section (simplified) of the microscope tube with the electron-optical system consisting of five lenses. L_1 condenser, S focusing device, L_2 objective lens (made in two parts), Q objective-aperture holder. This holder, and the specimen holder p, which cannot be seen in this drawing because it stands at right angles to the plane of the cross section, are illustrated in detail in fig. 13. B_1, B_2 holders of the selector diaphragm, L_3 diffraction lens, L_4 intermediate lens, L_5 projector lens. E centering device. (T specimen table, C camera with turning knob k_1, k_3 knob for the marking device X; see in the following text.)

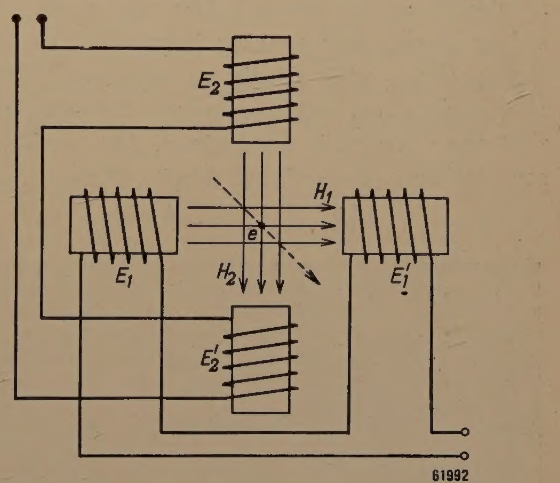

Fig. 11. Schematic representation of the centering device. e = electron beam perpendicular to the plane of drawing. The coils E_1, E_1' connected in series generate a magnetic field H_1, the coils E_2, E_2' a field H_2. The electron beam is deflected by the Lorentz force in a direction perpendicular to the resulting field at the place of the beam. By slightly varying the current through the two pairs of coils the resulting field can be varied in strength and direction and thus the electron beam deflected as far as may be necessary in any desired direction.

As a departure from other constructions, where the electron gun can be shifted or tilted in its entirety by means of flexible connections between the electron gun and the microscope tube, we have chosen the constructionally more attractive method of directing the beam by deflection with the aid of magnetic fields. This centering device can be seen at the top of the diagram in fig. 10 (E). It consists, in essence, of two pairs of coils, each pair supplying a magnetic field directed transversely to the beam. Its action is explained in *fig. 11*.

The specimen holder

The specimen is mounted on a very small silver plate with a rectangular opening and this carrier is clamped in the rod-like holder already mentioned (*fig. 12*). The holder is placed in what may be called the specimen table, a flat metal disc of non-magnetic material placed in the gap between the pole pieces of the objective lens. This disc can be shifted about 1 mm, by means of two pins, in two directions at right angles to each other and both perpendicular to the axis of the microscope tube. By a combination of these two movements any part of the small specimen can be brought into the centre of the object plane, thus making it possible to "scan" the specimen with a uniform movement. Rubber ring seals over and underneath the disc ensure that the vacuum is maintained. This sealing and some other constructional details of the specimen table and holder (and also of the holder for the objective aperture already discussed) are given in *fig. 13*.

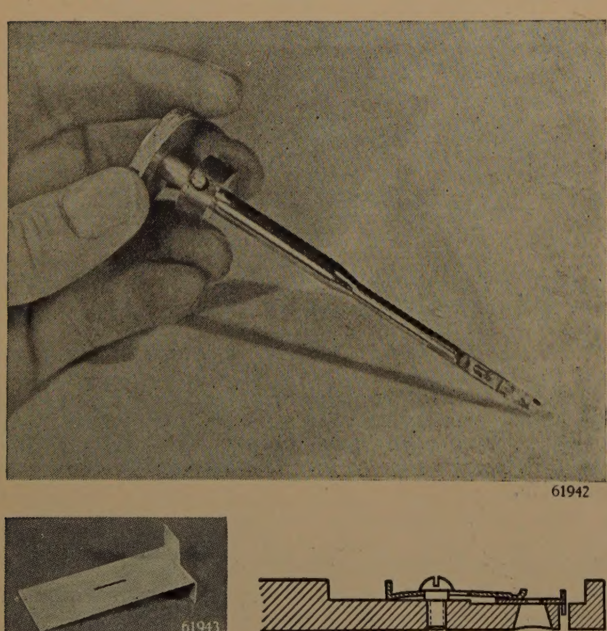

Fig. 12. The rod-like specimen holder, with underneath on the left (greatly magnified) one of the small silver plates acting as carriers for specimens. The drawing on the right below shows how such a plate is clamped in the holder.

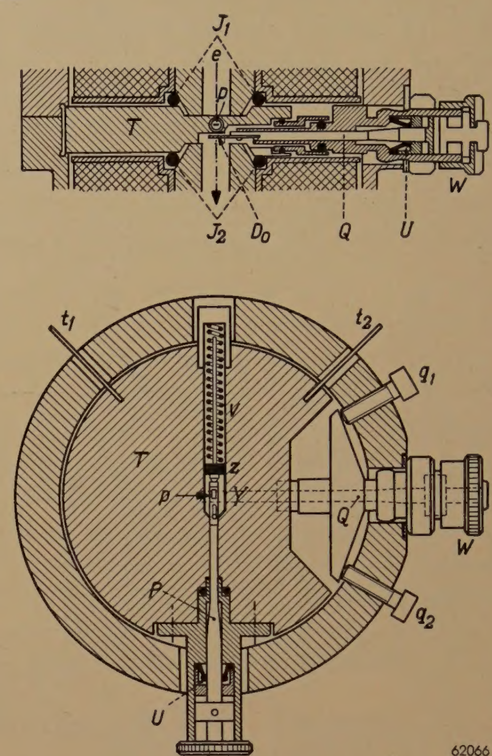

Fig. 13. The specimen table (T), into which the rod-like specimen holder P is inserted. t_1, t_2 pins for shifting the table, the vacuum being preserved by the rubber ring seals J_1, J_2. Y specimen lock with rubber piston z and spring v. Q holder of the objective aperture D_0, which is only a few mm away from the specimen. The axial displacement of this latter holder, for changing the two objective apertures, is brought about by turning the milled nut W, two stops being provided, each corresponding to the exact position of one of the apertures. In order to facilitate accurate centering of the small aperture in the axis of the microscope the guide for the holder rod Q can be swung round a little; this adjustment of the direction of Q is made with the set screws q_1, q_2. It is only needed if the holder has been entirely withdrawn, for instance for cleaning the diaphragm. U are rubber rings of the so-called oil-seal type.

The two pins just mentioned are operated with two knobs at the side of the fluorescent screen via a system of levers either side of the microscope tube. Thus the specimen table can be shifted while one is sitting in front of the desk and watching the image on the screen. The displacement of each pin can be read accurately to within 1μ on an illuminated dial, so that it is quite easy to find a certain part of the specimen again. The lever system is so constructed that in the event of any slight deformations of the desk (displacements of the lever bearings) no force is transmitted to the pins; thus the image is not shifted if, for example, someone should lean upon the desk! The specimen is shifted quickly and very smoothy, the frictional force to be overcome in moving the specimen table being no more than about 10 newton (1 kg).

It has already been mentioned that the specimen holder has a sort of "lock". The principle of this is to be seen in fig. 13. When the specimen holder is withdrawn a rubber piston is pressed by a spring into the opening through which the specimen holder is drawn out, thereby automatically closing that opening. When the holder is reinserted the piston is forced back, against the pressure of the spring. Only the small amount of air between the specimen rod and the bore in the table (some mm^3) gets into the microscope tube.

The rod-shaped specimen holder has also made it possible to devise an extremely simple method for making stereo-micrographs. Without disturbing the vacuum the rod can be turned over a small angle about its axis. This axis lies in the specimen plane, so that, as the rod is turned, the centre of the specimen remains in place. In this way two micrographs can be taken of the specimen in succession, differing only in that the electron beam passes through the specimen volume at a somewhat different angle. When these photographs are viewed in a stereoscope one sees a three-dimensional picture. Thanks to the great depth of focus of the electron microscope, corresponding parts in the two photographs are equally sharp, although the concerned part of the specimen was once in front of and once behind the exact object plane.

The camera and accessories

It is a remarkable fact that in electron-microscopy the photographically recorded picture shows more than the visual image on the fluorescent screen, such in contrast to other comparable instruments like the telescope and the optical microscope, where usually the reverse is the case. It is therefore only obvious that where an electron microscope is used one prefers the photographic method for purposes of observation. This also has the advantage that the instrument need not be kept engaged for studying the pictures, whilst moreover the pictures recorded in micrograms can always be referred to again.

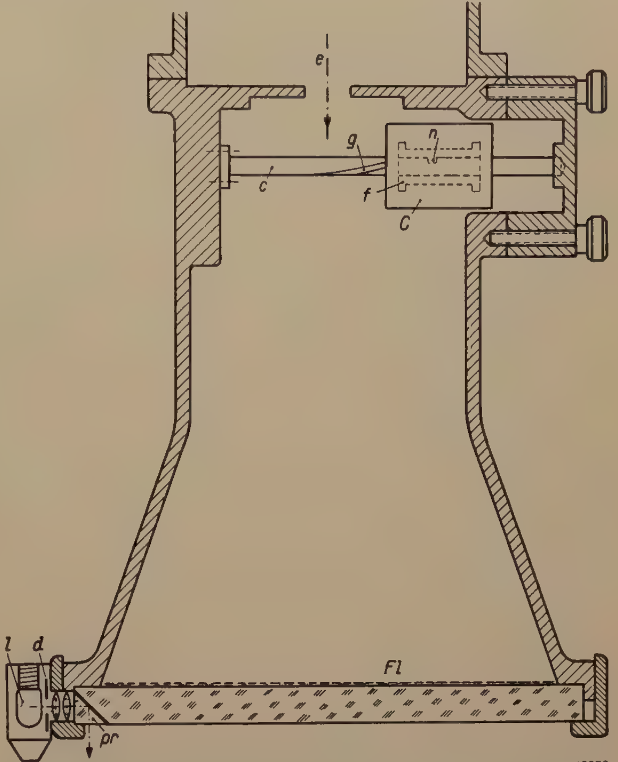

Fig. 15. Projection chamber of the microscope. Here the camere C is shown in the position of rest. To make a micrograph the camera is brought into the electron beam e by sliding it along the pin c. At the bottom of the drawing, on the edge of ths glass cover is a simple photometer for roughly determining the exposure time required for each picture. Via a small lens and a prism pr contained in a corner ground out of the glass cover, a small lamp l gives a spot of light seen by the observer beside the image on the fluorescent screen (Fl). The strength of this spot of light is varied with a diaphragm d, adjustable in four steps, until it corresponds as closely as possible to the brightness of the image on the screen. Once the sensitivity of the film is known the position of the diaphragm — the figures are illuminated by the lamp itself, so that they can be read in the dark — gives a measure for the exposure time required, the four positions corresponding to exposures in the ratio of 1 : 3 : 10 : 30. In practically all cases a more accurate determination is not needed. (For f, g and n see fig. 16.)

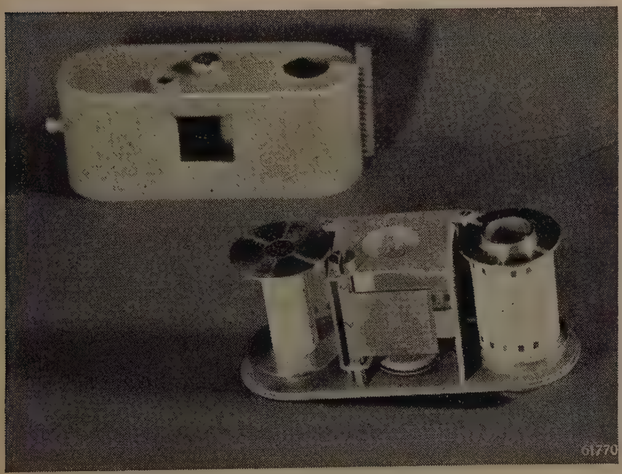

Fig. 14. The camera for 35 mm film used for recording the image.

In the case of our microscope the images are photographed on standard film of 35 mm width. The camera, illustrated in *fig. 14*, contains the two spools for winding and unwinding the film and a shutter in the form of a hinged cover. The film comes to lie at such a distance from the projector lens that the photographed image corresponds to a square of 14 × 14 cm on the screen, i.e. the square just fitting in the circle of 20 cm diameter. The spools offer space for a roll of film sufficient for 40 micrographs.

While visual observations are being made the camera is turned aside from the projection chamber, but still within the vacuum; see *fig. 15*. When a micrograph has to be made the camera is moved along into the electron beam by means of a knob provided for the purpose outside the microscope tube. With a second knob the shutter is opened and the electrons are thus allowed to fall upon the film. The exposure required is roughly determined by a simple, small, measuring device shown at the bottom of fig. 15.

The film is transported automatically with the movement of the camera: every time the camera is moved forward and back again the film is wound one picture frame farther, so that double exposures are precluded. The mechanism employed for this is similar to that used in a wimble, a to-and-fro movement being translated into a unilateral rotational movement. The mechanism is illustrated and further explained in *fig. 16*. When the film is completely exposed air is let into the microscope and the camera taken out, after removing a cover held with two screws.

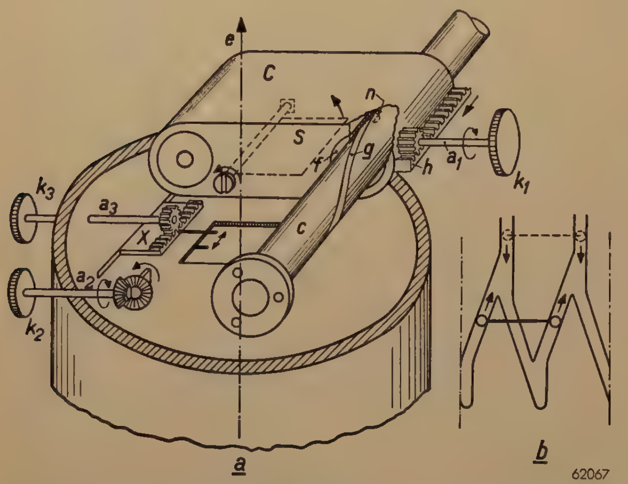

Fig. 16. Mechanism for operating the camera and automatic film transport (here the electron beam *e* is directed upward). *a*) The camera *C* is moved to and fro by means of the knob k_1 via the vacuum-sealed spindle a_1 and the ratchet-gear drive *h*. The knob k_2, which is turned with the other hand, opens the shutter flap *s*, via the spindle a_2. When the camera is moved it slides along a fixed pin *c* passing through the hollow bush of the film spool *f* on which the exposed film is wound. On this bush is a cam *n* directed inward which engages in a coiled groove *g* cut in the fixed pin. As the camera is moved along the pin the spool is thus caused to rotate, such that the film is wound up exactly half a picture length farther while the camera is travelling from the outermost position as far as it can go inwards. Upon the camera being returned to the outermost position again the cam follows a coiled groove in the opposite direction (leading back to the beginning of the first groove), so that the spool is rotated further in the same direction and the film is wound up another half picture length. The cam can never return along the same groove because of a freewheel coupling preventing a corresponding reverse rotation of the winding spool; one is therefore obliged to move the camera right along to the stop in both directions, thus precluding any possibility of partial overlapping of the photographs (double exposure). A counting mechanism on the knob k_1 shows how many of the 40 picture frames of the film have been exposed.

As a matter of fact there are two cams, and not one, running in two grooves in the one direction and in two opposed grooves in the other direction (see development of the pin in fig. 16*b*). Thanks to this double cam action only half a revolution of the film spool corresponds to the transport of a whole picture length; this spool therefore has twice the diameter, which has the advantage that there is relatively little variation in the length of film wound up from the first to the fortieth picture and thus little film need be wasted. Moreover the steeper grooves give a greater lateral force component on the cam, making it easier for the film spool to be rotated. *X* is a device for marking the scale on the micrographs.

Of course, if it is desired to develop and examine a certain microgram at once, the camera can be taken out before the film is completely exposed. While the work in the dark room is being done one can carry on with the microscope work with another camera previously prepared.

The scale can very easily be marked on each image that is to be photographed. Immediately underneath the projector lens, in the electron beam, are two parallel wires, the distance between which can be changed by means of a ratchet-gear drive (see *X* in fig. 16, with knob k_3 and spindle a_3). These wires cast two parallel shadow marks on a cm scale drawn close to the edge on the fluorescent screen. The distance between the wires is adjusted so that the distance marked off on the cm scale corresponds to 1 μ length in the specimen. The distance required between the marks follows directly from the magnification factor shown by a milliammeter measuring the excitation current of the intermediate lens or the diffraction lens. The 1 μ length thus marked off is, of course, correct at any point where the electron beam is intercepted, thus also on the film. In *fig. 17* a micrograph is reproduced which was made with our electron microscope and which clearly shows the 1μ marking.

For good micrographs to be obtained a very high degree of electrical and mechanical stability of the microscope is essential. The electrical stability will be discussed presently. As regards mechanical stability we have to stress once more the importance of the rigid construction of the microscope tube, in which no flexible connections of any kind have been used between the various parts. Even when all possible precautions have been taken (some of these will be mentioned) the transmission of small vibrations to the microscope tube cannot be entirely avoided. In order to test the sensitivity of our instrument to vibrations we introduced a vibrator in the desk by way of experiment, when it was found that the specimen holder vibrated with an amplitude of 2 μ. Although, with a magnification of 20,000 times, this should have resulted in an unsharpness of 4 cm on a fixed film, the microgram obtained was still perfectly sharp! Owing to the rigid construction the transmitted vibrations apparently caused all parts of the microscope tube, including the specimen holder, to vibrate as one whole, thus without affecting the picture quality at all.

a

b

Fig. 17. Micrograph of magnesium oxide taken with the Philips electron microscope at a magnification of 18,000 times. The cube-shaped crystals lie on a film of "Formvar" and the whole is "shadowed" with a stream of uranium vapour. At the top on the left-hand side of the photograph are the two scale markings, the distance between which represents a length of 1 μ. Photo *b* shows a detail of *a* at a magnification of 60,000 times.
A closer examination of the original micrograms shows that here the resolving power is better than 50 ångström. With factory-made microscopes built according to the design described here micrographs have already been obtained where the resolving power was found to be 25 ångström.

In conclusion of this part of the description of the electron microscope, in *fig. 18* a photograph is given in which the whole of the microscope tube is seen and in which some of the parts discussed can easily be identified.

The high-tension supply

The electrons can be accelerated with a voltage of 40, 60, 80 or 100 kV. The highest voltage — which is unusually high for an electron microscope of a commercial type — makes it possible to photograph even the thicker objects (viz. bacteria) occurring in normal investigations. The lower voltages may be required for examining extremely thin and light specimens, which at a higher voltage give pictures of less contrast. The lowest voltage may also prove useful for making micrographs under unfavourable vacuum conditions, for instance when the specimen or the film is giving off gas, which at a higher voltage would make it impossible to operate the tube.

In this connection it is well to touch upon a fundamental question, namely that of the **brightness** of the magnified images produced on the fluorescent screen. In the case of micro-projection with an optical microscope with the maximum useful enlargement of about 1000 times, the pictures are still sufficiently bright if the light source used has a brightness

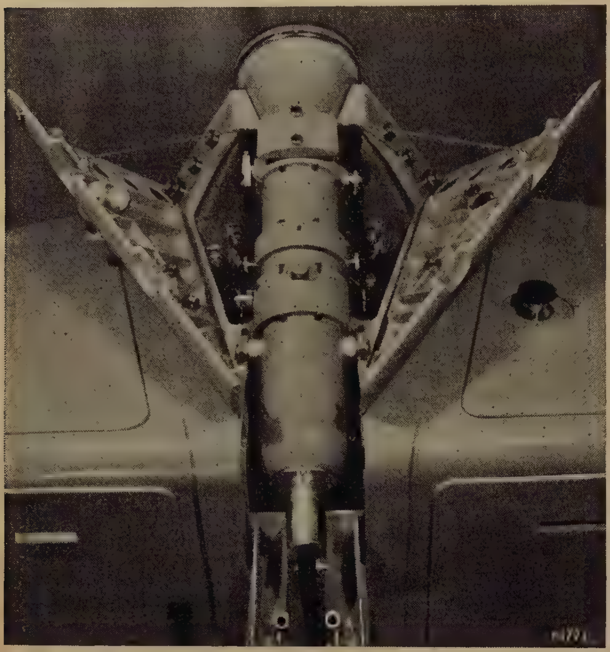

Fig. 18. Top view of the desk with the protective covers of the microscope tube thrown open. At the top the conical projection chamber, in the neck of which are the two knobs for operating the camera and the removable cover for taking the camera out. Halfway down the tube, on top, is the knob for the specimen holder, to the left of that, at the side of the tube, the knob for the objective aperture, and a little higher up, on either side of the tube, the knobs for the selector diaphragm.

of say 2000 candela/cm^2. For a 100 times larger magnification, however, a 10,000 times brighter light source would be required to get pictures of the same brilliancy, thus a light source about 100 times brighter than the sun! In electron-microscopy the situation is essentially analogous. To get a sufficiently bright fluorescent image with a magnification of 100,000 times an enormously "bright" beam is needed ("brightness" here is the energy per second, per unit of solid angle and per unit of apparent emitting surface). That this should be at all possible is only due to the fact that **additional** energy can be supplied to the beam of rays emitted and which illuminate the specimen, this being done by **accelerating** the electrons.

Thus it is seen that the high voltage does not serve the sole purpose of "hardening" the electrons to give them the power of penetrating through the specimen.

The high D.C. voltage is supplied by a cascade generator of a conventional type, consisting of a 50 kV transformer and a combination of two valves and two capacitors. The voltage is smoothed by a filter and adjusted to one of the four previously mentioned values by means of a variable ratio transformer preceding the high-tension transformer. A photograph of the generator which is mounted in an oil-filled casing is reproduced in *fig. 19*.

The position the generator occupies in the desk and its connection to the microscope tube by a rubber cable with earthed shield are to be seen in fig. 2. The cable runs behind the desk with a wide loop and is secured axially to the head of the microscope tube, so that sufficient play is left when the cathode end of the tube has to be opened for renewing the filament. The cable shield is connected air-tight to the earthed shield forming the head of the microscope tube — a construction similar to that found with "Metalix" X-ray tubes. Since there are no insulating surfaces exposed to the air, the instrument can be used even under unfavourable atmospheric conditions, and particularly under reduced atmospheric pressure (e.g. in laboratories high up above sea level), without any risk of flash-overs, via the insulation.

The focal length of a magnetic electron lens, energized by a current I, for electrons accelerated by a voltage V_0, is proportional to V_0/I^2 (at least so long as the iron of the pole pieces is not saturated; see formula (4) in the article quoted in footnote [1])). In order to get perfectly sharp micrographs it is therefore necessary that during say 30 seconds — about the longest time required for focusing an exposure — the accelerating voltage does not vary by more than 1/20,000 and the excitation currents by no more than 1/40,000.

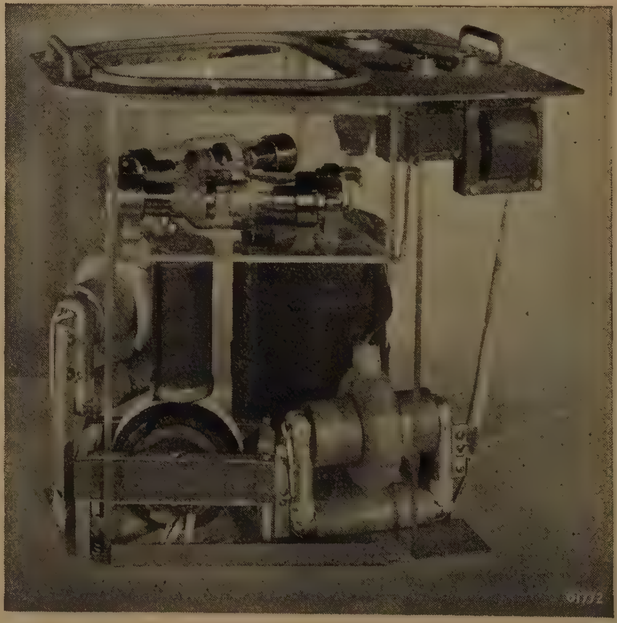

Fig. 19. The high-tension generator ready to be placed in the oil-filled tank. On the left at the bottom is the 50 kV high-tension transformer. On top of that is one of the capacitors and, still higher, the two valves for the cascade circuit (see the diagram in fig. 20); the second capacitor, together with the resistors and capacitors of the smoothing filter, is in the large cylinder on the right at the back. On the right at the front and on the extreme left, somewhat higher up, are the 100 kV insulated filament-current transformers for the cathode of one of the valves and for the filament of the electron gun.

There are various methods for stabilizing the high tension to the required degree. The most effective method consists in feeding back the fluctuations in the high tension to the high-tension generator [3]). In this way both the variations arising at the input (mains voltage fluctuations) and those arising at the output are counteracted. The output variations may be due, for instance, to reduced emission of the filament, variations in the filament voltage, release of traces of gas in the tube, or — to put it in general terms — to variations of the load. In our case, thanks to the connection of electron gun resembling a self-biased triode, the load of the generator is constant to a high degree, it thus being sufficient to stabilize the input voltage of the generator.

To this end, the generator is fed from a small valve oscillator (output 20 W) oscillating at a frequency of 100 c/s. The D.C. voltages required for feeding this oscillator are derived from a highly stabilized supply unit of known design [4]). *Fig. 20* is a circuit diagram of the complete high-tension generator.

The point gained in the method of stabilization employed is that it costs little trouble to keep a low D.C. voltage highly constant, and thus a highly constant A.C. output of the oscillator is ensured. Attempts to stabilize direct the alternating voltage of the mains and to use this as input for the high-tension generator, for instance by means of the known stabilizers with transductors, were doomed to failure in our case, because these stabilizers have too much inertia to smooth out surges and are also too sensitive for mains-frequency fluctuations nowadays so often occurring.

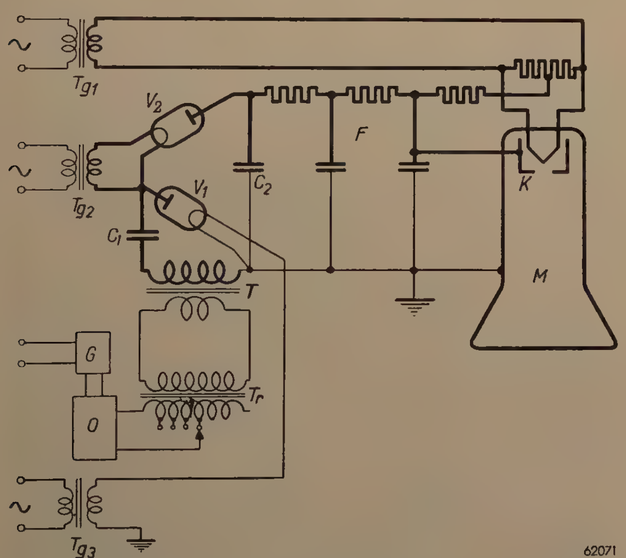

Fig. 20. Circuit of the high-tension generator. T high-tension transformer, C_1, C_2 capacitors and V_1, V_2 valves of the cascade circuit, T_r variable-ratio transformer, T_{g1}, T_{g2}, T_{g3} filament-current transformers, F smoothing filter, M microscope tube with cathode K and earthed anode. The generator is fed from the valve oscillator O (frequency 100 c/s) which receives the necessary anode and filament voltages from the stabilized supply unit G. The high-tension parts are drawn in heavy lines.

The choice of 100 c/s for the valve oscillator made it possible to use a high-tension transformer of a normal type frequently used in X-ray apparatus. With higher frequency it would have been necessary to have a transformer of a special low-capacitance construction.

Wherever accelerated electrons come into collision with matter they generate X-rays. This is especially the case on the condenser aperture, which receives roughly half the electrons emitted. The metal jacket of the microscope tube and the iron jackets of the lens coils make it unnecessary to take any special measures for protection of the user against the X-rays from this source. More attention had to be paid, however, to the X-rays generated on the fluorescent screen. These rays, it is true, only reach an appreciable intensity when there is the strongest possible concentration of the electron beam upon the specimen and the smallest magnifications are used, but this source of X-rays is very close to the observer's face. Consequently, in order to render this radiation harmless, the thick covering window of the microscope tube has been made of lead glass and the shield round the projection chamber lined with lead. The X-ray dose that may possibly be received during an 8-hour working day is therefore no more than 1/100th to 1/10th of the tolerance dose permitted in the various counties.

Energizing of the electron lenses

As already pointed out, the windings of the magnetic lenses have to be energized with a current that does not vary by more than 1 : 40,000 during 30 seconds. A stabilized supply unit like that mentioned above (see footnote [4])) cannot supply this energizing current direct; it supplies a constant voltage, whilst the resistance of the lens windings changes rather considerably with the temperature (in spite of the water cooling, the temperature is by no means to be regarded as constant). By modifying the circuit described in the article quoted [4]), however, a power pack can be constructed

[3]) See, e.g., A. C. van Dorsten, Stabilization of the accelerating voltage in an electron microscope, Philips Techn. Rev. 10, 135-140, 1948.
[4]) H. J. Lindenhovius and H. Rinia, A direct current supply apparatus with stabilized voltage, Philips Techn. Rev. 6, 54-61, 1941.

which yields a constant current. The system adopted by us is represented in a simplified form in *fig. 21* and explained in the caption. Roughly it can be said that the system has the tendency to keep the voltage constant between the points

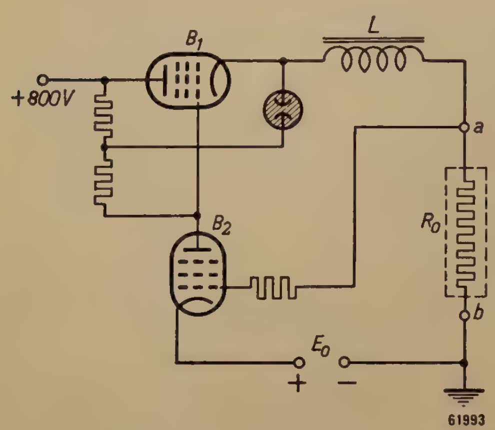

Fig. 21. Simplified circuit of the power pack supplying a constant current for an electron lens. The voltage drop across the constant resistor R_0 increases with the current flowing through the lens coil L, so that the control grid of the pentode B_2 (type EF6) becomes less negative, the current through B_2 increases, its anode potential drops and thus the control grid of the pentode B_1 (type EL51) becomes more negative, thus counteracting the tendency of the current through B_1 (= current through L) to rise. — The greater the amplification factor of the two valves and the higher the resistance of R_0, the more sensitive is the regulation and thus the smaller the resulting current fluctuations. In order to obtain the required grid bias for B_2 at a high value of R_0, the voltage drop across R_0 is compensated by a sufficiently high opposed voltage E_0 ($\approx$ 75 V). This voltage, which acts as a reference voltage, must of course be highly constant.

a and *b* and, since there is an accurately adjusted resistor R_0 with an extremely low temperature coefficient between those points, the current flowing through this resistor, which is the same as the current for energizing the lens winding L, is likewise kept highly constant.

The current can be adjusted to the desired value by varying the resistor R_0. This implies that a separate power pack according to fig. 21 is needed for each lens that has to be varied in strength independently of the others. This is the case with the diffraction lens and the intermediate lens respectively for varying the magnification, and also with the condenser lens for adjusting the "illumination". The focal lengths of the objective lens and the projector lens, on the other hand, the first of which has to be only slightly variable for focusing, can be coupled together. In all, therefore, we have three power packs. These, together with the common, small, stabilized unit supplying the constant reference voltage (E_0 in fig. 21), are shown in *fig. 22*.

The objective lens and the projector lens are interlinked by connecting the windings of these two lenses in series, with counterwise direction of the current. This has the advantage that the image rotations caused by the two lenses (see the caption of fig. 3) practically compensate each other. During focusing, therefore, no trouble is experienced from image rotation.

Also when varying the magnification, by adjusting the energizing current for the intermediate or diffraction lens, there is no image rotation worth mentioning, thanks to these lenses working with only a relatively small enlargement and thus in themselves causing hardly any image rotation.

When varying the accelerating voltage V_0 of the electrons it is necessary to change also the energizing currents for all lenses in order to get the same focal lengths (the variation required is inversely proportional to $\sqrt{V_0}$; see above). Each of the three power packs therefore has, for the four steps of the high tension, four different resistors R_0 which are automatically switched over when selecting the value of the high tension (with the large switch knob seen on the front of the desk in fig. 2). When the voltage is changed there is therefore hardly any need, if at all, to readjust the lenses.

The path followed by the electrons must not be

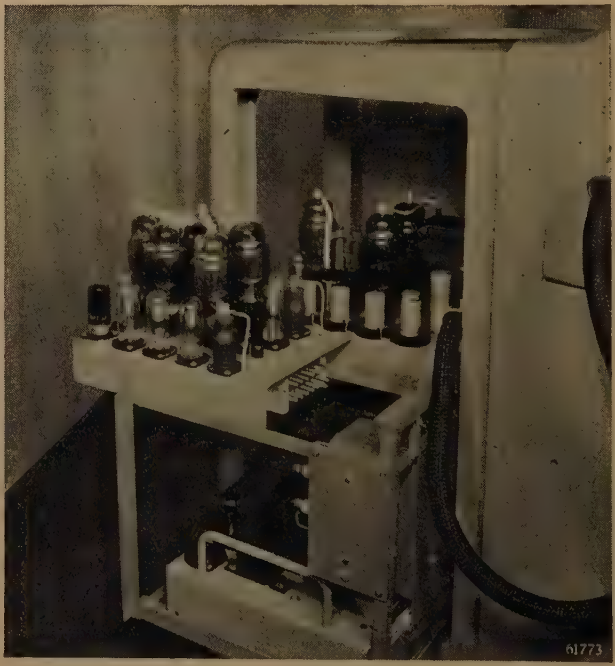

Fig. 22. Drawn-out chassis with the three power packs for the condenser lens (max. 100 mA), the diffraction or the intermediate lens (max. 100 mA) and the objective and projector lenses (max. 400 mA). Owing to the higher currents required for the last two lenses this power pack has three EF 51 valves connected in parallel, instead of the one pentode B_1 (fig. 21). At the back is the stabilized supply unit for the constant reference voltage E_0.

influenced by foreign magnetic (or electric) fields. In some microscopes this has had to be specially provided against, but in our microscope this has not been necessary because the lens coils with their iron jackets directly joining up with each other already form a very effective screening.

The vacuum system

To be able to work the microscope tube with 100 kV the pressure inside the tube must be lower than 10^{-4} mm Hg. Since, when working with the microscope, the vacuum is repeatedly disturbed and has to be restored, a rapidly acting and easily operated pumping system is essential. The system employed here is represented in *fig. 23*. It comprises

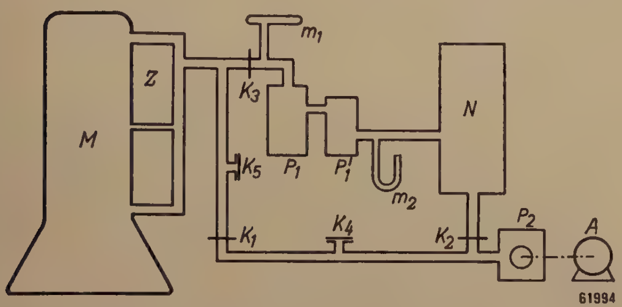

Fig. 23. Schematic diagram of the vacuum system. M microscope tube, Z pumping line, P_1, P_1' high-vacuum pumps, P_2 fore-vacuum (rotary oil) pump driven by the motor A; the high-vacuum pumps are water-cooled, the cooling system being connected in series with that for the electron lenses. N fore-vacuum tank, m_2 manometer for recording the fore-vacuum, m_1 Penning manometer for the high vacuum; the neon glow-lamp serving as indicator for the latter manometer can be seen through a slit in the front panel of the microscope desk (fig. 1). K_1-K_5 valves.

two high-vacuum pumps in series, viz. an oil-diffusion pump and a small mercury-vapour jet pump serving as a booster pump, capable of pumping at a rate of about 10 litres/sec at 10^{-4} mm Hg, and further a fore-vacuum pump (rotary oil pump) and a fore-vacuum tank. The pump line is connected to the microscope tube in three places: two wide connections are made to the cathode and projection chambers and a narrower one at the level of the selector diaphragm (see fig. 2). Thus when the air is being pumped out it does not have to travel through the whole of the microscope tube with its narrow passages. The connections are sealed off with rubber rings, in such a way that any vibrations from the high-vacuum pumps are not transmitted to the microscope tube.

The microscope is evacuated in four stages:

1) the microscope tube is pre-evacuated, the high-vacuum pumps being pre-heated;
2) the fore-vacuum tank, with the permanently connected high-vacuum pumps, is pre-evacuated;
3) the microscope tube is connected to the high-vacuum pumps;
4) the fore-vacuum tank is disconnected from the rotary oil pump and the latter stopped (at the same time air is admitted above the oil in this pump to prevent the oil from rising and entering the pump line).

Under normal conditions the whole cycle, starting with the microscope filled with air under atmospheric pressure, takes about 2 minutes [5]). When stage 4 has been reached, the fore-vacuum tank and the specimen lock enable the microscope to be used for several hours on end and a large number of specimens can be examined before it becomes necessary to switch on the rotary oil pump again for a few minutes.

The various necessary connections between the pumping lines are made with valves, which are easier to operate than the classical cocks. The lines have been so arranged that all these valves could be contained in one single valve box. All the connections that have to be made according to the above system are brought about by turning one single knob, driving a cam shaft inside the valve box which has a cam of appropriate profile for operating each valve as required.

In addition to the four positions corresponding to the four stages of pumping mentioned above, the valve-operating knob has a fifth position, the zero position (0) in which the microscope is shut off from all the pumps and atmospheric air can be let into the microscope by means of an inlet valve operated with a push-button. A filter in this valve line keeps out moisture and dust.

Operation of the instrument; safety measures

In the foregoing description of the Philips electron microscope stress has been laid on the measures taken for facilitating the operation of this instrument: the centering of the electron beam, the focusing of the image, checking of the apertures, insertion of the specimen, making micrographs, replacement of the filament, single-knob operation of the vacuum system.

The principle of single-knob operation and automatic control is applied in more than one connection in this microscope. Mention has already been made of the voltage selector, which automatically changes

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[5]) This cycle always has to be passed through after a new film has been put in. Then, too, the microscope can be evacuated in two minutes, but only if the film has been stored in a dry place. If this simple precaution has not been taken then the evacuation may take hours, owing to the moisture absorbed by the gelatine layer of the film being only very slowly released.

the lens currents at the same time. Another example is the adjustment of the magnification: one knob covers the whole range of magnifications, from 1000 times to 60,000 times. The switching over from the diffraction lens to the intermediate lens, necessary for changing over from enlargements smaller than 4000 times to stronger magnifications, is done automatically with the same knob. Yet another example is the focusing device. Deflection is started simply by pressing a button, which is kept pressed in so long as one is adjusting the objective lens current. Finally, there is again the vacuum system: the spindle of the knob already referred to is also fitted with a control drum switching on the motor of the rotary oil pump in the positions 1, 2 and 3 and switching it off in the positions 4 and 0.

A number of measures have been taken to safeguard the instrument against damage through breakdowns or faulty manipulations. The control drum just referred to, coupled to the operating knob for the vacuum system, has an additional contact operating a relay in such a way that high tension can only be applied to the microscope tube when that knob is in position 4. Thus it is impossible for the high tension to be switched on by mistake before the tube has been evacuated, which would cause a gas discharge in the tube. If, however, the manometer should not have been properly watched and the knob prematurely turned to position 4, or if through some fault or other the vacuum in the tube should fail, nothing can even happen then, because an overload switch in the earth lead of the high-tension circuit trips the high tension as soon as the emission current in the tube exceeds 3 mA, a value corresponding to the occurrence of a glow discharge which does no damage to the microscope tube nor to the generator. Further, the knob for the vacuum system is fitted with a locking device which permits of its being fully turned in one direction only: for a complete cycle, from the air being admitted up to the tube being evacuated again, the knob has always to be turned from the zero position (0) through the positions 1, 2, 3 and 4 back to 0, in that order. If it were possible for the knob to be turned by mistake from 0, after air has been admitted into the tube, the wrong way round direct to position 4, in which the tube is connected to the high-vacuum pumps, then — owing to the large amount of air that they would suddenly be called upon to cope with — these pumps would be thrown out of proper working order for some hours. (For the same reason the push button used for admitting air into the tube is locked, so that it can only be pressed in in the zero position.)

Then there is also to be mentioned the safety switch fitted in the outlet of the water-cooling system. In the event of a stoppage in the circulation of the water the excitation of the electron lenses is automatically switched off, and also the heating of the high-vacuum pumps, so that no mercury vapour or oil vapour can get into the microscope tube. Simultaneously the heating of the high-vacuum pumps is automatically switched off — and then it is also impossible to switch on the high tension — if through some cause or other the fore-vacuum, measured by the mercury manometer m_2 in fig. 23, is insufficient. This safety device works with a relay which is switched on as soon as the mercury column of the manometer reaches a contact fitted in at a certain level.

Pilot lamps on the operating panel show at a glance what the situation is as regards the high tension, the water cooling and the fore-vacuum; instruments, some of which have already been mentioned, register the pressure inside the microscope tube, the magnification setting, the emission current, the filament current and the exposure time required, whilst there is also a check on the stabilization of the high tension.

This lengthy description may well have demanded some patience on the part of the reader, and also the impression that must have been gained from our introduction, namely that an electron microscope is not exactly a simple instrument, will no doubt now be more deeply rooted. It is well to realize, however, that the complexity of this electron microscope is for a large part not to be ascribed to the principle of the instrument and certainly does not involve proportional problems for the user. On the contrary, this seeming complexity results from the aims of the designers to relieve the user as far as possible of the burden of having to pay so much attention to this and that and from the necessity of having to make so many manipulations. As in so many other cases in modern engineering, part of the human work is transferred to the machine so that the operator can concentrate more on the possibilities that the machine offers him.

Summary. In the Philips electron microscope the microscope tube proper is mounted at an angle on a desk. The image is produced on a fluorescent screen 20 cm in diameter. Mounted in the desk is the high-tension generator, the pumping system and the supply apparatus for the electron lenses. The electron-optical system, based on principles developed by Le Poole, consists of five magnetic lenses. In addition to the usual condenser, objective and projector lenses there is an intermediate lens and a diffraction lens, by means of which the magnification can be continuously varied from 1000 times to 60,000

times, with the screen entirely covered, and one can change over immediately from the normal image of a specimen to an electron-diffraction diagram.

The microscope tube, with all the lenses, forms a rigid and accurately adjusted unit. The electron beam is centered in the tube with the aid of a set of deflection coils. The objective lens is so constructed that the object plane lies in the gap between the pole pieces (thus not in the bore). The specimen, as also the objective aperture, can therefore be moved into place from the side by means of a simple rod-like holder. A kind of air lock limits the amount of air entering the microscope to only a few mm^3 when exchanging specimens, and it takes no more than 20 seconds to restore the vacuum. The objective aperture and other diaphragms can easily be checked for centering and examined for contamination, and if necessary readjusted and cleaned. Neither is there any trouble in replacing the previously centered filament in the electron gun.

The images are photographed on standard 35 mm film. The sliding camera, with a film spool for 40 photographs, is within the vacuum. The camera is moved into the electron beam and the shutter opened from the outside, the film being automatically transported further. Focusing of the image is facilitated by a "wobbling" beam device.

The lenses are cooled with water and energized by three power packs supplying stabilized currents of maximum 100 and 400 mA. The accelerating voltage can be varied in four steps from 40 to 100 kV, the excitation currents of the lenses being thereby automatically adjusted so as to retain the image. The high-tension generator load is kept highly constant owing to the self-biased electron gun. Thus the necessary stabilization of the high tension is made possible merely by keeping the A.C. input voltage highly constant, this being achieved by employing a valve oscillator for the supply.

The fore-vacuum and high-vacuum pumps are operated in the right sequence by one manifold control knob. Various locking devices and safety switches safeguard the instrument against damage through breakdowns or faulty manipulations. Working with the microscope is further facilitated by various means, such as a device for uniform scanning of the specimen and for finding any part of the specimen again, an exposure meter, a marking device for indicating the scale on each photograph, etc.

AN EXPERIMENTAL "STROBOSCOPIC" OSCILLOSCOPE FOR FREQUENCIES UP TO ABOUT 50 Mc/s

I. FUNDAMENTALS

by J. M. L. JANSSEN.

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The highest frequency for which a sensitive cathode-ray oscilloscope of conventional design can be constructed is limited by various circumstances to about 10 Mc/s. An artifice makes it possible, however, to reach much higher frequencies. This artifice consists in the application of an electrical analogy of stroboscopic exposure, the commonly known method for studying periodical movements taking place so quickly that the eye cannot follow them. With the oscilloscope described here the stroboscopic flashes of light are replaced by electrical pulses which scan, as it were, the voltage curve that is to be examined and convert it into a phenomenon of low periodicity, which can then be viewed on the screen of a cathode-ray tube in the normal way.

Highest frequency attainable with oscilloscopes of conventional design

Cathode-ray oscilloscopes of the conventional type consist of a cathode-ray tube with electrostatic deflection, an amplifier for the voltage to be examined (vertical deflection), a device producing a sawtooth voltage for the time base (horizontal deflection) and some other parts with which we are not concerned here. Each of the three component parts mentioned sets a limit upon the highest frequency that can be properly observed in the oscillogram.

If, as the frequency is increased, the duration of a cycle of the deflection voltage becomes comparable to the time taken by the electrons to traverse the space between the deflection plates, a transit-time effect occurs in the cathode-ray tube. With an accelerating voltage of, say, 1000 V this effect becomes noticeable at frequencies of the order of 100 Mc/s.

The amplifier sets a much lower limit. If the amplification is to be kept independent of the frequency also at high frequencies, the amplification per stage has to be reduced to a low level, so that in order to get good sensitivity a large number of amplifying stages are required [1]). Moreover, there is a still more stringent requirement to be made of the amplifier for an oscilloscope, namely that the components of a non-sinusoidal voltage must be faithfully reproduced not only in amplitude but also in phase. Furthermore the amplifier must be capable of supplying a considerable reactive current. In fact, at a frequency of, say, 10 Mc/s the anode capacitance of the output valve and the parallel capacitance of the deflection plates together form an impedance of only something like 1000 ohms, so that with a voltage of, say, 100 V between the plates the capacitive current amounts to about 100 mA. A frequency of 10 Mc/s can therefore be regarded as being roughly the upper limit for which an oscilloscope amplifier can be built that answers reasonable requirements.

Together with the frequency of the voltage to be examined there is, of course, also the frequency of the time base to be raised. The highest frequency at which a sufficiently large sawtooth voltage can be generated with reasonable linearity and with short flyback time is about 1 Mc/s. If the frequency of the voltage to be examined (the voltage across the pair of vertical deflection plates) is, say, 10 Mc/s then the oscillogram never comprises less than about ten cycles, a number which for various purposes is more than is desirable.

In the normal Philips oscilloscopes so far produced lower frequency limits than those mentioned have had to be chosen in order to avoid having to make these oscilloscopes for a wide range of applications unnecessarily heavy and expensive. Thus the maximum frequency for the vertical deflection of the type GM 3152 oscilloscope [2]) is 1 Mc/s and that of the type GM 3159 [3]) 0.5 to 1 Mc/s (according to the sensitivity), whilst for both these types the highest time-base frequency is 150 kc/s. There are other types where, for special reasons, these limits are still lower.

Naturally there is also a need for an oscilloscope

[1]) See e.g. H. J. Lindenhovius, G. Arbelet and J. C. van der Breggen, A millivoltmeter for the frequency range from 1 000 to 30 × 10⁶ c/s, Philips Techn. Rev. 11, pp. 206-214, 1949/1950 (No. 7).

[2]) Philips Techn. Rev. 4, 198-204, 1939.

[3]) Philips Techn. Rev. 9, 202-210, 1947.

for frequencies higher than 1 Mc/s. Instead of developing such an oscilloscope along the traditional lines, offering but little prospect of reaching frequencies higher than 10 Mc/s, we have found it preferable to strike out in an entirely different and more promising direction. In view of the resemblance it shows to the principle of stroboscopic exposure the oscilloscope that has now been devised has been called the "stroboscopic" oscilloscope.

This first article explains the fundamentals of the stroboscopic method, whilst a further article will be devoted to the electrical design of the various components.

Principle of the stroboscopic oscilloscope

When positive voltage pulses of constant amplitude are fed to the anode of, for instance, a pentode (*fig. 1*), whilst there is only a (negative) D.C. voltage on the control grid (this voltage not cutting the valve off), then the anode current consists of pulses of an amplitude depending upon the control-grid voltage. When in addition a small alternating voltage v_o is applied to the control grid and the frequency f_o of that voltage is equal to the repetition frequency f_i of the pulses on the anode (*fig. 2a*), then the anode-current pulses all have the same amplitude, this being determined inter alia by the phase of the pulse with respect to the A.C. grid voltage. The same thing holds when f_o is an exact multiple of f_i (fig. 2*b*). But if f_o deviates somewhat from f_i, or from nf_i (where n is a whole number), then the phase of each pulse with respect to the alternating voltage differs from that of the preceding one (fig. 2*c*). The pulses then lag or lead with respect to the alternating voltage and thereby scan that voltage point by point. Thus the anode-current pulses vary in amplitude and form, as it were, a series of snapshots of the amplitude of the alternating voltage. The lowest frequency f_z occurring in the anode current equals the absolute value of the difference between f_o and nf_i. If the voltage to be examined contains m harmonics of frequencies $2f_o$, $3f_o$, mf_o then the frequencies $2f_z$, $3f_z$, mf_z also occur in the anode current.

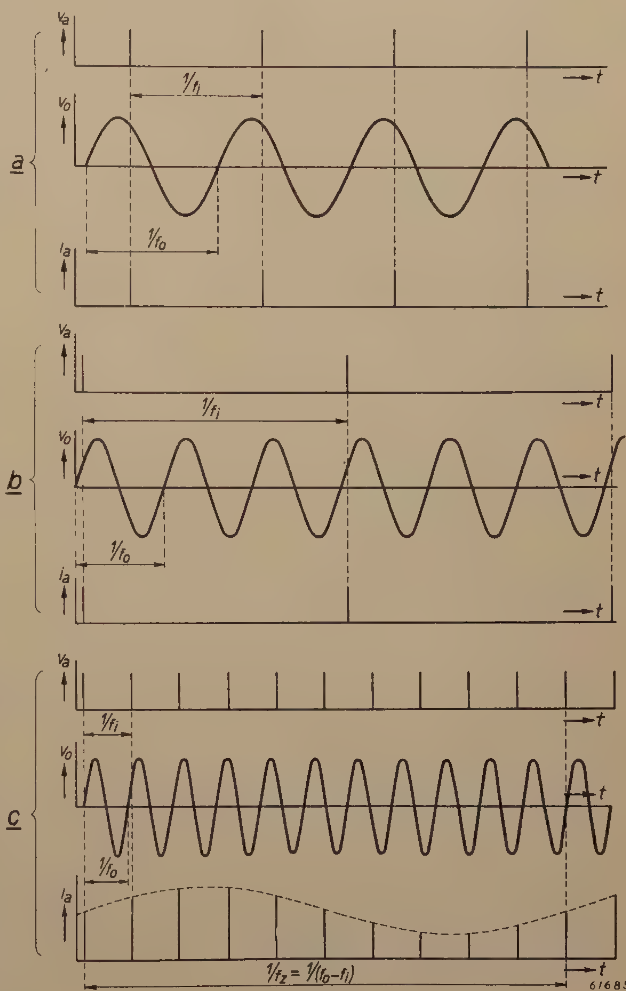

Fig. 2. Diagrammatic representation of the mixing process, representing as functions of the time t: v_a = voltage pulses applied to the anode, v_o = alternating voltage on the control grid of the mixing valve, i_a = anode current pulses. At (*a*) the frequency f_o of v_o is equal to the repetition frequency f_i of the pulses, at (*b*) $f_o = 3 f_i$ and at (*c*) there is a small difference between f_o and f_i. In the last case the series of anode-current pulses forms a point-by-point reproduction of v_o and the frequency $f_z = f_o - f_i$ (generally $|f_o - nf_i|$) takes the place of f_o.

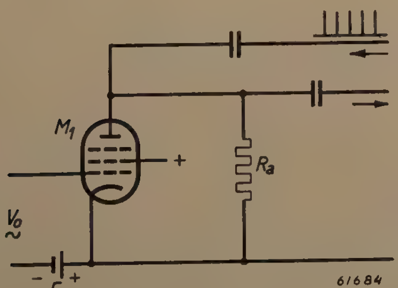

Fig. 1. Circuit of a mixing valve (pentode M_1) in which the alternating voltage v_o to be examined is mixed with voltage pulses fed to the anode. R_a anode resistor from which the output voltage is taken.

The analogy with stroboscopic exposure becomes evident here: in the two cases first mentioned ($f_o = f_i$ and $f_o = nf_i$) the pulses correspond to synchronous flashes of light, whereby the exposed, periodically moving object (frequency f_o) is made to appear to be quite stationary; in the case corresponding to that where f_o differs somewhat from nf_i on the other hand the object appears to be moving slowly. It is this latter case with which we are concerned in the designing of the "stroboscopic" oscilloscope: the amplitudes of the anode-

current pulses form "reproductions" (albeit only of a finite number of points) of the alternating voltage at the control grid, and the fundamental frequency of the anode current, $f_z = |f_o - nf_i|$, can be made much lower than f_o. It is in this latter possibility that the essential advantage of the stroboscopic method lies for those cases where f_o is beyond the range of an ordinary oscilloscope.

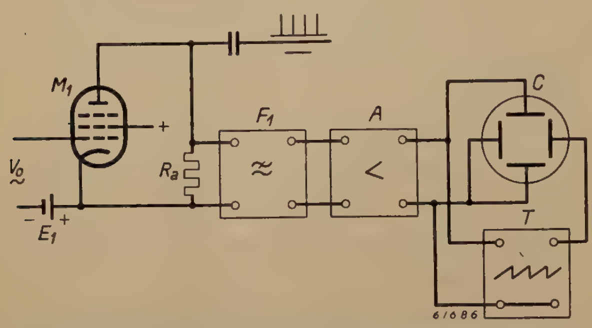

Fig. 3. Block diagram of a stroboscopic oscilloscope with uniform scanning. v_o the voltage to be examined, M_1 mixing valve with an anode resistor R_a, F_1 low-pass filter, A low-frequency amplifier, C cathode-ray tube, T generator of a sawtooth voltage the frequency of which is synchronized with the frequency f_z taken from the amplifier A.

A stroboscopic oscilloscope could in principle be devised in the following way: a resistor R_a (fig. 1 and *fig. 3*) is inserted in the anode circuit of the pentode (from now on we shall call this the *mixing valve*, since in this valve the voltage v_o is mixed with the impulses [4])); with the aid of a low-pass filter only the low frequency components (f_z and its multiples) are extracted from the voltage across R_a, this filter output then being amplified and fed to the vertical deflection plates of a cathode-ray tube.

To give the oscillogram a linear time scale the voltage for the horizontal deflection has to be given the shape of a linear sawtooth voltage, since the phase of the scanning pulse with respect to the alternating voltage to be examined increases linearly with time. Furthermore, in order to get a stationary picture the sawtooth voltage has to be given the frequency f_z (or a frequency of which f_z is a multiple).

The repetition frequency f_i of the pulses has to be so adjustable that a multiple of this frequency, nf_i, can be brought close enough to f_o to give $f_z = |f_o - nf_i|$ a value lying below the cut-off frequency of the filter. And this has to be the case for all values of f_o between the widest possible limits; thanks to the factor n, which can be chosen at will, f_i only needs to be adjustable within a limited range. If v_o contains harmonics up to and including the m^{th}, then mf_z must also be passed by the filter.

Although it is in principle possible for an oscilloscope to be arranged along these lines, great difficulties would be encountered in its execution. With f_o, say, = 30 Mc/s, and thus nf_i differing but little from that value, the variation in time of f_i would have to be much less than can be realized in practice; even 0.1% variation of nf_i means a change of 30 000 c/s in f_z. As a consequence f_z, and still more so any multiples of f_z, would then come to lie above the cut-off frequency of the filter. Moreover, it would be impossible to keep the sawtooth generator of the time-base voltage synchronized with such a variable f_z.

With the method described below this difficulty is avoided and, furthermore, another possibility is opened.

Phase modulation of the pulses

With the method applied by us the pulses are periodically *modulated in phase* (or in position, if this term is preferred). This means a modulation of the repetition frequency f_i, the average (or *central*) value of which, f_{ic}, is so chosen that $nf_{ic} = f_o$.

On the *average*, therefore, the pulse generator is synchronized with the frequency f_o. Without phase modulation the pulses would continuously be scanning the *same* point of the voltage curve (fig. 2*b*), but by "moving them to and fro" — that is to say, by periodically modulating them in phase — they are made to scan *different* points of the v_o curve.

In place of the phase difference increasing linearly with time, as with the previous method, we therefore have here a phase difference varying according to a periodical function of time. It is not of primary importance *what* periodical function is chosen for this, but in order to have a linear time scale the voltage chosen for the horizontal deflection must be the *same* periodical function of time as that of the phase difference. For both functions one could use, for instance, one and the same sawtooth function, but it is simpler to use a sinusoidal function, especially if it is given the *frequency of the mains*; it will be shown presently why such a low frequency is advantageous. This is illustrated in *fig. 4*, where in the diagram (*a*) a cycle of the voltage v_o to be examined is represented (superposed upon a grid bias E_1) and in the diagram (*b*) the

[4]) The ratio of the amplitude of the anode-current component with frequency f_z to the amplitude of the fundamental wave of v_o will also be called here the conversion conductance.

scanning pulse is shown in the state of rest (without phase modulation). When the phase φ of the pulse is made to change sinusoidally with the time t, then upon swinging from $-\pi$ to $+\pi$ (fig. 4c)

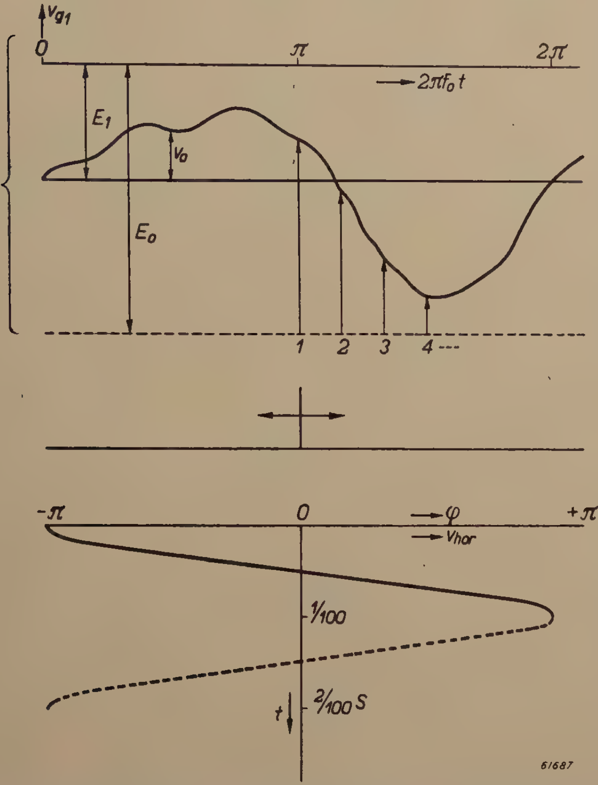

Fig. 4. Scanning with phase-modulated pulses. *a*) Grid voltage v_{g1} of the mixing valve, consisting of the bias E_1 and the voltage v_0 to be examined. At the grid voltage E_0 the valve is just cut off. *b*) State of rest of the voltage pulse on the anode. *c*) Phase φ of the pulses swinging about the state of rest, and the voltage v_{hor} for the horizontal deflection, as function of the time t plotted vertically downwards. The frequency of φ and v_{hor} is the mains frequency (50 c/s).

the pulse scans a number of points of the v_0 curve in succession. In fig. 4*a* the vertical arrows *1, 2, 3* ... — drawn from the level E_0, i.e. the grid voltage at which the mixing valve is just cut off on the occurrence of a pulse — indicate the amplitude of several successive anode-current pulses, which are the "snapshots" of the v_0 curve. The low-frequency components of the anode current, with the frequency of the phase modulation and a series of multiples of that frequency (inherent in the frequency spectrum of the phase modulation), bring about the vertical deflection of the electron beam in the cathode-ray tube. The horizontal deflection is brought about by v_{hor} (fig. 4*c*) varying synchronously with the movement of the pulse. The screen of the cathode-ray tube then shows a curve which — provided the instantaneous reproductions are sufficient in number — is a faithful picture of one cycle of the v_0 curve.

During the return movement of the pulse (φ varying from $+\pi$ to $-\pi$ according to the dotted part of the sinusoidal line in fig. 4*c*) the pulse could be made to scan the same v_0 curve again, the spot of light on the screen then describing the same curve as before but in the reverse direction, since v_{hor} then changes in the opposite sense. Better use can be made of the return stroke by causing the pulse to scan another voltage curve, so that the oscillograms of two voltages (v_{oI} and v_{oII}) can be obtained simultaneously. (v_{oII} may possibly be zero, in which case the spot of light describes the zero line on the return stroke.) We shall see in a subsequent article how the alternate scanning of two curves can be brought about with the aid of a simple electronic switch.

In fig. 4 the amplitude of φ (the "phase sweep" of the pulse) has been made equal to half a cycle of v_0, so that exactly one whole cycle of the v_0 curve is scanned. There is nothing, however, to prevent the sweep being made larger or smaller so as to be able to scan a part of the curve that is more or less than one cycle. Since this scanning takes place in the same interval of time (1/100th sec) as that in which the horizontal movement completes one half cycle, the part scanned always covers the full width of the oscillogram. By giving the pulse a small sweep and making the state of rest around which it sweeps adjustable, any part of the v_0 curve can be observed as it were microscopically. This is of great value for studying a certain detail, a possibility which does not exist when applying the method previously mentioned (pulses proceeding at constant speed along the v_0 curve).

Fig. 5 shows how a stroboscopic oscilloscope with sinusoidal phase-modulated pulses can be designed. (Although it is not customary to use phase modulation of the light flashes in actual

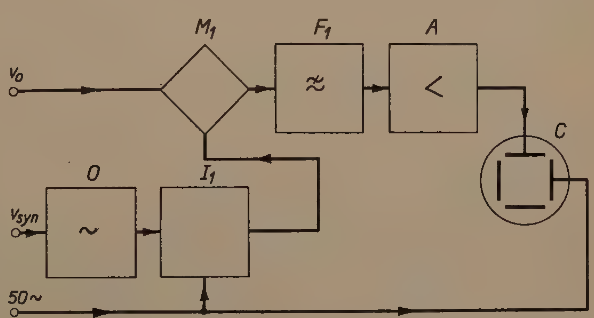

Fig. 5. Elementary block diagram of a stroboscopic oscilloscope with sinusoidal phase modulation. v_0, M_1, F_1, A and C as in fig. 3. I_1 pulse generator a harmonic of which is synchronized via the oscillator O with the synchronization voltage v_{syn} (synchronous with v_0). I_1 is phase-modulated by the mains voltage.

stroboscopy the term "stroboscopic" is nevertheless used here.) As was the case with the system shown in fig. 3, vertical deflection is brought about by the output voltage of the mixing valve M_1 via a filter and an amplifier. An oscillator O, supplying a sinusoidal voltage, is synchronized with an externally applied voltage $v_{\rm syn}$, which has to be synchronous with v_o ($v_{\rm syn}$ may in fact be the voltage v_o itself). The output voltage from this oscillator synchronizes in turn a pulse generator I_1, to which in addition a sinusoidal voltage v_φ of 50 c/s is applied for modulating the pulse in phase. The frequency of the oscillator is the same as the repetition frequency of the pulses, for which we have chosen — for reasons which will be explained later — a central value f_{ic} of approximately 100,000 c/s; f_{ic} is so adjusted that a multiple of it is just equal to the frequency f_o.

These components will be described in further detail in a subsequent article.

Limitations of the stroboscopic oscilloscope

We shall now first investigate what limitations have to be considered in the case of a stroboscopic oscilloscope and how far these set limits to the uses of such an apparatus.

In the foregoing it has been shown that the "data" of the oscillogram consist only of a finite number of points (the peak values of the anode-current pulses; see, e.g., fig. 2*c*). The question is in how far these points are able to give a faithful picture of the original v_o curve in spite of the gaps in between them.

The second point that we have to consider more closely is the duration of the pulses. So far we have tacitly assumed it to be infinitely small. Of course such pulses cannot be realized, and we must therefore work with pulses of a finite duration. Just as the finiteness of the duration of a stroboscopic flash of light causes a certain kinetic blurring of the object observed, so with a finite duration of the electrical pulse certain details of the v_o curve become lost; in other words, the resolving power of the pulses with which we have to work is not unlimited.

We shall now deal with the question of the gaps between the pulses and then with that of the duration of the pulses.

Gaps in the oscillogram

If the v_o curve contains m harmonics then it is defined by $2m + 1$ points of a cycle, since this number of points determines the $2m + 1$ coefficients of the Fourier series, namely m coefficients of the sine terms, m coefficients of the cosine terms and the constant term (D.C. voltage component). Given that the cycle of the curve has p points, then — notwithstanding the gaps between these points — the curve is completely determined if $p \geqq 2m + 1$, or

$$p > 2m \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

If this condition is not satisfied the best approximation that can be derived from the inadequate data is the curve having no more than $m' = \frac{1}{2}p < m$ harmonics corresponding to the data. In order to reproduce with a stroboscopic oscilloscope as many harmonics as possible this apparatus has to be so designed that the picture consists of the largest possible number of points. This means that the rate of scanning (the speed at which the pulses move along the v_o curve) has to be as low as possible.

To work this out quantitatively let us first assume that we again have to do with the case with which we began our considerations about the stroboscopic oscilloscope, namely that of a constant repetition frequency f_i of the pulses of which the $n^{\rm th}$ harmonic differs somewhat from the fundamental frequency f_o of the voltage v_o. The rate of scanning is then constant, corresponding to the constant differential frequency $f_z = |f_o - nf_i|$ and with equidistant "measuring data" (anode-current pulses). It is easily verified that f_i/f_z is the number of points p with which one cycle of the v_o curve is scanned. Therefore, in order to observe even the $m^{\rm th}$ harmonic of this curve, provision has to be made to satisfy the condition

$$\frac{f_i}{f_z} > 2m. \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

A similar condition holds for the method actually applied where the pulse is modulated in phase and consequently also in frequency. The "measuring data" are now no longer equidistant as in the case considered above, but for small instantaneous values of the phase sweep ($\varphi = 0$), where the pulse has a high scanning speed, these "data" lie farther apart than is the case with large instantaneous values ($\varphi = +\Delta\varphi$ or $-\Delta\varphi$), where the scanning speed is only low. In other words, the middle part of the oscillogram produced is built up from fewer data than the parts to the left or right of it. In order to get the same "density of measuring data" in this middle part as is obtained with uniform scanning, it is therefore necessary that the condition (2) shall be satisfied when the maximum value is substituted for f_z.

Since the frequency $\nu = 50$ c/s with which the phase modulation takes place is very low compared with $f_{ic} \approx 100{,}000$ c/s, we may regard the situation as being quasi-stationary and speak of the momentary repetition frequency f_i' of the pulses sinusoidally swinging about the central repetition frequency $f_{ic} = f_o/n$. We then have a variable differential frequency $f_z' = |f_o - nf_i'|$, for which, as will be derived below, we find the expression $|\nu \cdot \Delta\varphi \cdot \sin 2\pi\nu t|$ (where $\Delta\varphi$ is the phase sweep of the pulses expressed in radians of the v_o curve).

If $2\pi f_{ic}t + \psi$ is the phase of the unmodulated pulse (ψ being an arbitrary constant) then the phase of the modulated pulse can be written as $2\pi f_{ic}t + \psi + (\Delta\varphi/n)\cos 2\pi\nu t$, where $\Delta\varphi/n$ is the phase sweep expressed in radians of the series of pulses.

The momentary angular frequency of the pulses is defined as the derivative of the phase with respect to time [5]), i.e. $2\pi f_{ic} - 2\pi\nu \cdot (\Delta\varphi/n) \cdot \sin 2\pi\nu t$, and the momentary frequency f_i' itself is therefore

$$f_i' = f_{ic} - \nu \cdot (\Delta\varphi/n) \cdot \sin 2\pi\nu t \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

For the momentary differential frequency f_z' we then find $f_z' = |f_o - nf_i'| = |\nu \cdot \Delta\varphi \cdot \sin 2\pi\nu t|$, since $nf_{ic} = f_o$.

Substituting for f_z in (2) the maximum value of $f_z' = |\nu \cdot \Delta\varphi \cdot \sin 2\pi\nu t|$, i.e. $f_z'{}_{\max} = \nu \cdot \Delta\varphi$, we get

$$\frac{f_{ic}}{\nu \cdot \Delta\varphi} > 2m \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

For the case where exactly one cycle of the v_o curve is scanned we must have $\Delta\varphi = \pi$ radians (cf. fig. 4c), so that (4) then becomes

$$\frac{f_{ic}}{2\pi\nu} > m \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4a)$$

From these formulae it appears that it is favourable to choose a high central repetition frequency f_{ic} of the pulses and a low frequency for the phase modulation (ν). As regards the latter it is an obvious solution to choose for ν the mains frequency; any lower frequency would have to be specially generated, whilst moreover there would soon be a flickering of the picture to contend with, since the time base also has to have the frequency ν.

With $f_{ic} \approx 100{,}000$ c/s (see the following section) and $\nu = 50$ c/s we find from (4a), for the scanning of a complete cycle, that the highest harmonic that can be observed is given by $m = 10^3/\pi \approx 300$. If less than one cycle is scanned ("microscopic scanning", $\Delta\varphi < \pi$) then the resolving power reaches to harmonics $\pi/\Delta\varphi$ times as high.

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[5]) See e.g. Th. J. Weyers, Frequency modulation, Philips Techn. Rev. 8, 42-50, 1946, and in particular page 44.

It might be thought that the formulæ (4) and (4a) hold only for the very special case where f_{ic} and thus also f_o are exact multiples of ν, since then with each sweep the same points of the v_o curve are scanned every time, and that in all other cases therefore, where different points are scanned every time, the said conditions need not be complied with. Such, however, is not the case. A closer analysis shows that it is a question of the number of points scanned by one sweep of the pulse, regardless of the question whether following sweeps cover the same points or different ones; it is thus independent of chance values of the ratio f_{ic}/ν. As a matter of fact the relations (4) and (4a) will presently be derived once more in a manner which shows this independency.

Duration of the pulse

In the foregoing section we have seen that with infinitely small pulses the v_o curve to be examined can only be displayed with harmonics of up to a limited order (m), independently of the fundamental frequency f_o. This limitation is due to the gaps. The following will show that actually the finite width of the pulse sets an absolute limitation upon the frequency for which a stroboscopic oscilloscope can be used. If the v_o curve contains harmonics of a frequency higher than this limit $f_{\max}$ then those harmonics are not reproduced (or at most but poorly), even though their order may not exceed the above-mentioned limit m.

When the oscillation time of the voltage to be examined becomes of the same order as the duration τ of the pulses, then the conversion conductance of the mixing process and thus the sensitivity of the instrument rapidly diminishes. The frequency limit $f_{\max}$ may therefore be said to be of the order of $1/\tau$.

To define this more precisely it has to be borne in mind that when the frequency is equal to $1/\tau$ the sensitivity is zero, at least when the pulses are rectangular (*fig. 6*), since at that frequency the

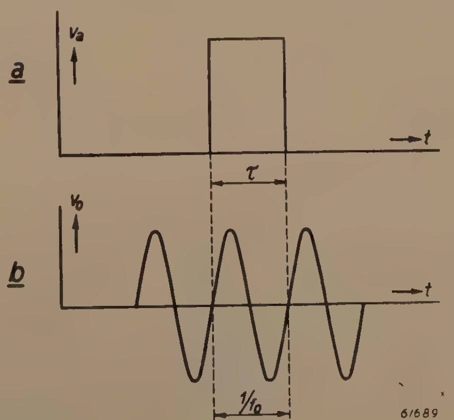


Fig. 6. Rectangular anode voltage pulse v_a of which the duration τ is exactly equal to one cycle $1/f_o$ of the voltage v_o to be examined.

width of the pulse just matches one cycle of the voltage v_o, so that the contribution that the average value of the anode current of the mixing valve receives from the positive half of this cycle is exactly cancelled by the contribution from the negative half, and thus the conversion conductance is nil.

In a subsequent article we shall show that the pulses used have roughly the shape of a half sine. With this shape of pulse the rule also holds that the conversion conductance is nil at a frequency of $1/\tau$, if τ is understood as being a kind of average width of the pulse corresponding to about $^2/_3$ of the width at the base.

To allow for a sufficiently wide margin away from the state where the conversion conductance is zero one can take as the frequency limit

$$f_{\max} \approx \frac{1}{2\tau} \cdot \quad \ldots \ldots \ldots \quad (5)$$

With a pulse duration of the order of 10^{-8} sec — in a subsequent article it will be shown what difficulties stand in the way of generating pulses of shorter duration — it follows that $f_{\max} \approx 50$ Mc/s.

Using the results obtained in the preceding section we can arrive at an equation connecting the central repetition frequency f_{ic} of the pulses, the frequency ν of the phase modulation and the frequency limit $f_{\max}$ (or the pulse duration τ).

Suppose that the fundamental frequency of the voltage v_o to be examined is of the lowest value that can be considered for stroboscopic scanning, thus $f_o = f_{ic}$. Let us also assume that the highest (m^{th}) harmonic of v_o has exactly the frequency $f_{\max}$. Then $m = f_{\max}/f_{ic}$. And at the same time it is desired that the m^{th} harmonic is just the highest that can be reproduced in view of the gaps, so that the condition (4) holds. Let the phase sweep be such that, measured on the scale of the frequency f_{ic}, which always has about the same value, it amounts to π radians. In the case considered heie ($f_o = f_{ic}$) the phase sweep is then likewise π radians on the scale belonging to f_o and thus just sufficient for scanning one cycle of the v_o curve; in other cases ($f_o > f_{ic}$, $n > 1$) more than one cycle can be scanned. The condition (4) now has to be applied in the form (4a), and with $m = f_{\max}/f_{ic}$ this becomes:

$$\frac{f_{ic}}{2\pi\nu} > \frac{f_{\max}}{f_{ic}}$$

or

$$f_{ic}^2 > 2\pi\nu f_{\max} \approx \frac{\pi\nu}{\tau}.$$

From this equation it follows that, with τ in the order of 10^{-8} sec and $\nu = 50$ c/s, $f_{ic} >$ about 100,000 c/s. Since the repetition frequency of the pulses forms the lowermost limit of the frequency range of the oscilloscope, in order to keep this range as wide as possible f_{ic} has not been chosen any higher than is necessary, hence about 100,000 c/s, the value frequently mentioned in the foregoing.

Cut-off frequency of the filter

The required cut-off frequency of the low-pass filter (F_1 in fig. 5) is directly related to the value of f_{ic}, as will be understood from what follows.

At (*a*) in *fig. 7* part of the frequency spectrum of the phase-modulated pulses has been drawn: it shows the fundamental frequency f_{ic} and some harmonics, $(n-1)f_{ic}$, nf_{ic} and $(n+1)f_{ic}$, which would already be present in the case of unmodulated pulses, and also the side bands due to the phase modulation; the distance between two adjacent lines of the side bands is the modulation frequency ν. At (*b*) in this diagram we have represented the single-line spectrum of the voltage v_o (any harmonics of v_o are of no consequence here); this line lies at $f_o = nf_{ic}$. Mixing of the two spectra produces innumerable differential frequencies (the differences between f_o and all frequencies of the spectrum of

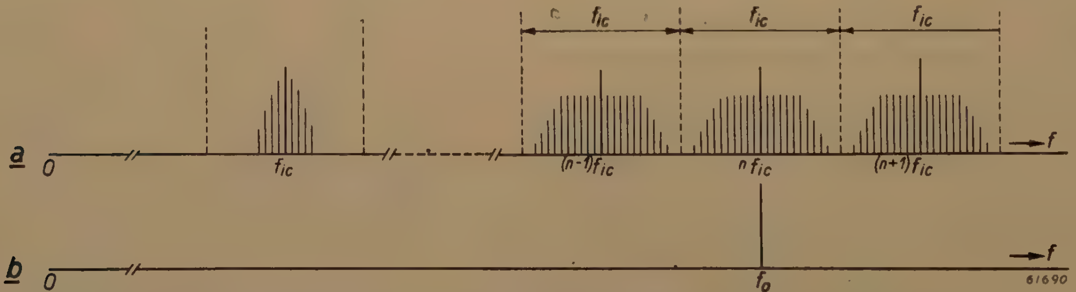


Fig. 7. Frequency spectrum, (*a*) of the phase-modulated pulses, (*b*) of the sinusoidal voltage v_o. (At (*a*) neither the number of components of the side bands nor the intensity of the components are true to scale; it is only a schematic indication that the side bands of the multiples of f_{ic} are richer in components than the side bands of f_{ic} itself, and that the outermost components of the side bands are much weaker than the majority of the components lying farther inwards.)

the modulated pulses). Of all these frequencies the filter should pass only those derived from f_o and the side bands of nf_{ic}; frequencies which are the difference of f_o and other side bands — in particular the adjacent side bands of $(n - 1) f_{ic}$ and $(n + 1) f_{ic}$ — have to be suppressed. From this it follows that the cut-off frequency of the filter must not exceed $f_{ic}/2 \approx 50{,}000$ c/s.

From these considerations it also follows that the side bands should not overlap, hence that their width should not be more than $f_{ic}/2$; in other words in fig. 7 they should not extend beyond the vertical dotted lines. Strictly speaking they actually do, because they consist of an infinite number of terms, but if, as is the case here, the situation is to be regarded as quasi-stationary ($\nu \ll f_{ic}$) the part of the side band falling outside the frequency sweep is of so small an amplitude as to be negligible.

The condition that has to be satisfied to ensure that the side bands do not overlap is, therefore, that none of the multiples of the pulse frequency may have a greater frequency sweep than $f_{ic}/2$. For the n^{th} harmonic (belonging to the fundamental frequency f_o) the frequency sweep is $\nu \cdot \Delta\varphi$, as follows from the equation (3) derived in the foregoing. If the v_o curve contains harmonics with m as the highest order then the corresponding multiple $mn \times$ (pulse frequency) makes the sweep $m\nu \cdot \Delta\varphi$. This is the largest of all frequency sweeps that have to be considered, and the fact that this must be smaller than $f_{ic}/2$ immediately leads to

$$\frac{f_{ic}}{2\nu \cdot \Delta\varphi} > m,$$

and, with $\Delta\varphi = \pi$ (scanning of one cycle of f_o), to

$$\frac{f_{ic}}{2\pi\nu} > m,$$

so that we have again arrived at the formulae (4) and (4a) by a different method.

The electrical design of a number of components of an experimental stroboscopic oscilloscope, such as the pulse generator, the system for synchronization, etc., will be dealt with in a further article.

Summary. A new principle is described for a cathode-ray oscilloscope which is very promising for the investigation of voltages with very high frequenties and shows a close connection with the known stroboscopic principle. According to this principle the voltage to be examined is mixed in a mixing valve with a pulsatory, phase-modulated voltage; the central repetition frequency of the pulses is so chosen that some multiples of it is exactly equal to the frequency of the voltage to be examined. The anode current of the mixing valve consists of pulses which produce, as it were snapshots in a low-frequency rhythm, of the voltage examined. The low-frequency components of the anode current are filtered out and used for the vertical deflection in the cathode-ray tube. Without phase modulation of the pulses these would "scan" the same point of the voltage curve every time, but by periodically modulating the pulses in phase they can be made to scan at will either a larger or a smaller part of the curve, depending upon the extent of the phase sweep. A stationary picture with linear time scale is obtained on the screen of the cathode-ray tube by arranging for the horizontal deflection to take place according to the same time function as that for the phase modulation. It is advantageous to choose for this time function a sinusoidal function having the mains frequency. Consideration is given to the influences of the gaps between the "snapshots" from which the oscillogram has to be reconstructed, and of the finite duration of the pulses used.

THE DISTRIBUTION OF ILLUMINATION ON A PLANE PARALLEL TO A TUBULAR LAMP

by J. LOEB *).

535.245.1:628.932.1

The lamps used prior to the invention of the tubular fluorescent lamp can almost invariably be regarded as point sources of light. Text books on illumination engineering show how the illumination from such lamps can be determined in a given plane. Now that tubular lamps are becoming of more general use it is of importance to have a method by means of which the illumination in a given plane can easily be calculated for this kind of lamp too. With the method described here it is only necessary to consult a simply arranged table that is easily compiled.

Regarding the calculation of the illumination when using tubular lamps, two articles [1]) [2]) have already been devoted to this subject in this journal. Several investigations dealing with the same problem have also been published in other periodicals; in particular mention is made of a treatise by K. Norden [3]) published in 1908.

Now that tubular lamps, and especially tubular fluorescent lamps, are becoming of more and more general use it is of importance that everyone having to make calculations of the illumination when using these lamps should have at his disposal the means for determining these illuminations in a simple manner.

Since the diameter of a tubular lamp is always small compared with its length, there is no objection to the lamp being considered, diagrammatically, as a line of light. In this article, therefore, we shall always speak of linear sources of light. In some investigations an approximative solution is considered sufficient, the linear source of light being regarded as a point source. In practice such an approximation suffices if the point for which the calculation has to be made is a reasonable distance away from the lamp (cf. [1])), but for accurate calculation of the illumination at shorter distances from the lamp we shall avoid any such approximation. We shall assume, however, that the radiation from the lamp follows Lambert's law.

In this article we shall confine our considerations to a study of the direct illumination on a horizontal plane obtained from a linear source of light (or number of sources of light parallel to the plane) situated on a higher horizontal plane, for instance against the ceiling of the locality. This is the situation most commonly occurring in practice, where it is often desired to know what illumination is obtained on a horizontal table, for example in a workshop, from a general lighting at ceiling level or local lighting from lamps parallel to the plane of the table. This calculation can be made for lamps with and without fixture. It is also possible to determine in like manner the distribution of the illumination in any plane with respect to the lamp, allowance being made, moreover, to a sufficient approximation, for the light reflected from the ceiling and the walls of the location in which the lamp is installed [4]).

Lamp without fixture

Let us first consider the case where a linear source of light is used without fixture. Assume the lamp to be of the length l and mounted horizontally along the ceiling at a height h above the horizontal work plane. With the aid of *fig. 1* we shall now

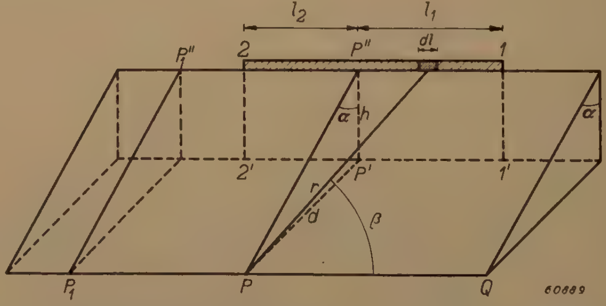


Fig. 1. Calculation of the illumination in a point P of a horizontal plane yielded by the element dl of a lamp fixed to the ceiling. *1* and *2* are the extremities of the lamp. The other figures and letters in the diagram are explaned in the text.

*) Lampes Philips S.A., Geneva.

1) N. A. Halbertsma and G. P. Ittmann, Illumination by means of linear sources of light, Philips Techn. Rev. 4, 181-188, 1939.

2) H. Zijl, The calculation of lighting installations with linear sources of light, Philips Techn. Rev. 6, 147-152, 1941.

3) K. Norden, Beleuchtungsberechnungen für Quecksilberdampflampen, Elektrotechn. Z. 28, 757-758, 1907, and 29, 883-886, 1908. See also E. L. Matthews, Das Licht 1, 141-146 and 165-168, 1931.

4) See J. Loeb, Méthode générale de calcul de la répartition des éclairements dans les installations d'éclairage par lampes à fluorescence et autres sources linéaires, edited by Lampes Philips S.A., Geneva, 1948.

calculate what illumination an (infinitely small) element dl of the lamp produces in a point P of the work plane. The extremities of the lamp are denoted by *1* and *2* and their projections on the work plane by *1'* and *2'*. Further, the distance PP' from P to the line $1'2' = d$, and $P'1' = l_1$, $P'2' = l_2$. The radius vector from P to dl, of the length r, makes an angle β with the line PQ parallel to the lamp. Finally, arc tan $d/h = \alpha$.

If the luminous intensity of the element of the lamp (in a direction perpendicular to its axis) is $I_0 dl$ then the illumination at P perpendicular to the radius vector is $I_0 dl \sin\beta/r^2$. The horizontal illumination corresponding to this is

$$dE = \frac{I_0 dl \sin\beta}{r^2} \cdot \frac{h}{r} \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

For a linear source of light the value of I_0 (the luminous intensity per unit length in a plane perpendicular to the lamp, in cd/m) can be derived from the luminous flux quoted by the manufacturers. This amounts to $\Phi/\pi^2 l \approx 0.1\ \Phi/l$, where Φ represents the luminous flux in lumens and l the length in metres. It must be borne in mind, however, that the definition of luminous intensity used in illumination engineering is based upon point sources of light, the luminous intensity of a lamp in a certain direction being determined by the luminous flux radiated in a small solid angle about that direction divided by that angle. In the case of linear sources of light this definition applies only when the observations are taken at a distance that is large compared with the dimensions of the lamp.

In the case of a point source of light the illumination (in lux) in a given point can be determined with the aid of a luxmeter and, if the distance from the lamp is known, from this it is possible to find the luminous intensity (in candelas). When the lamp is linear one can only deduce from the reading of a lux meter an "equivalent luminous intensity" of the source of light.

The factors dl and r in the second half of formula (1) will now be expressed in terms of h, α and β. Obviously $dl = r d\beta/\sin\beta$, and considering that $r = \sqrt{d^2 + h^2}/\sin\beta$ and $\sqrt{d^2 + h^2} = h/\cos\alpha$, we find that $r = h/\cos\alpha \sin\beta$. Substituting these expressions for dl and r in equation (1) the latter is transformed into:

$$dE = \frac{I_0 h \cos^2\alpha \sin^2\beta\, d\beta}{h^2} = \frac{I_0}{h} \cdot \cos^2\alpha \sin^2\beta\, d\beta. \quad (2)$$

The total illumination at P is found by integrating (2) between the limits β_1 and β_2, where $\beta_1 = \sphericalangle QP1$ and $\beta_2 = \sphericalangle QP2$.

We can therefore distinguish two cases. First we assume that the plane through P perpendicular to the lamp intersects the latter (in a point P'') as indicated in fig. 1. In this case, we shall first calculate the part $\int_{\beta_1}^{\pi/2}$ of the integral $\int_{\beta_1}^{\beta_2}$. This gives the illumination at P insofar as it comes from the part *1-P''* (length l_1) of the lamp, for which we find:

$$E_1 = \frac{I_0}{h} \cos^2\alpha \int_{\beta_1}^{\pi/2} \sin^2\beta\, d\beta =$$

$$= \frac{I_0}{h} \cos^2\alpha \left(\frac{\pi}{4} - \frac{1}{2}\beta_1 + \frac{1}{4}\sin 2\beta_1\right). \quad (3)$$

The position of the point P is determined by the distance d and the length l_1. Since $\cos\alpha = 1/\sqrt{1 + d^2/h^2}$ and $\tan\beta_1 = \sqrt{1 + d^2/h^2}\,.\,(h/l_1)$, from formula (3) E_1 can be calculated if d, l_1 and h are known. The factors (f) by which I_0/h has to be multiplied to arrive at the value of E_1 can be calculated and tabulated once for all for a number of values of d/h and l_1/h.

So far we have considered only a part of the lamp. The illumination E_2 given at P by the part *2-P''* (length l_2) of the lamp can, however, be calculated in exactly the same way. When d/h and l_2/h are known we can find this result from the same table of values as mentioned above. The total illumination E at P is then equal to the sum of E_1 and E_2.

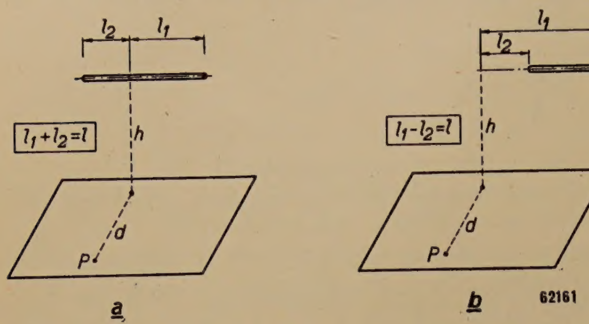
Secondly, we shall consider the case where the plane through P, perpendicular to the axis of the lamp, intersects the latter at a point on the extension of the axis (P_1'' in fig. 1). For l_1 we now have to take the distance from P_1'' to *1* and for l_2 that from P_1'' to *2*. Denoting again the illuminations from the hypothetical lamp parts P_1''-*1* and P_2''-*2* by E_1 and E_2 respectively, then $E_1 - E_2$ gives the total illumination at P_1. (When P_1'' in fig. 1 lies on the other side of the lamp then it has to be regarded as the difference between the fictitious lamp parts P_1''-*2* and P_1''-*1*.)

Table 1 is the practical development of this discussion. It makes it quite easy to calculate the illumination in a point of the work plane whose position is determined by the distances d and l_1 (or l_2) when h has been measured and I_0 is known. If the light comes from a number of lamps in one or more planes parallel to the work plane then the total illumination in a point of the work plane is found by adding the illumination obtained from each lamp separately.

Lamp with fixture

To get a general picture of the distribution of the illumination on a horizontal measuring plane it is obvious that we must imagine a series of planes perpendicular to the axis of the lamp and then see how the illumination varies along the lines of intersection of these perpendicular planes with

Table I. The factors f for calculating the horizontal illumination E in a point P of the work plane.



For case (a):

$$E = I_0/h\,[f(d/h,\, l_1/h) + f(d/h,\, l_2/h)]$$

For case (b):

$$E = I_0/h\,[f(d/h,\, l_1/h) - f(d/h,\, l_2/h)].$$

l_1/h, l_2/h \ d/h	0	0.25	0.50	0.75	1.0	1.5	2	3	5
0.10	0.10	0.09	0.07	0.05	0.03	0.02	**0.01**	—	—
0.20	0.20	0.18	0.14	0.10	0.08	0.03	**0.02**	0.01	—
0.30	0.28	0.26	0.20	0.15	0.10	0.05	**0.03**	0.01	—
0.40	0.36	0.33	0.26	0.19	0.13	0.07	**0.03**	0.01	—
0.50	0.43	0.40	0.32	0.23	0.16	0.08	**0.04**	0.02	—
0.75	0.56	0.52	0.42	0.31	0.23	0.12	**0.06**	0.02	0.01
1.0	0.64	0.60	0.49	0.37	0.27	0.14	**0.08**	0,03	0.01
1.5	0.72	0.68	0.56	0.44	0.33	0.18	**0.11**	0.04	0.01
2	0.75	0.71	0.59	0.47	0.36	0.21	**0.12**	0.05	0.01
5	0.78	0.74	0.63	0.50	0.39	0.24	**0.15**	0.07	0.02
∞	0.79	0.74	0.63	0.50	0.39	0.24	**0.16**	0.08	0.03

the measuring plane. For such a perpendicular plane both l_1 and l_2 are constant. The factors by which I_0/h has to be multiplied for the successive points of the lines are found by taking the figures from one of the horizontal lines in table I (for the given l_1/h) and adding or deducting the corresponding figures in a second horizontal line (those for l_2/h).

We now suppose that the lamp is provided with a cylindrical fixture of the same length as the lamp and so narrow that the whole may be regarded as linear, and we shall assume that the radiation from the lamp and the fixture follows Lambert's law. Owing to the presence of the fixture the I_0 first used has to be multiplied by a certain factor depending upon d/h.

In order to find this factor we imagine that, from a point in a flat plane perpendicular to the lamp, vectors are plotted in each direction proportional to the I_0 of that direction. The line connecting the extremities of these vectors is then, for this plane, the distribution curve of the transversal luminous intensities I_0 depending upon the angle α [5]). In the case of a lamp without fixture this curve is a circle, for I_0 is then independent of α. Where the light source is in a fixture this distribution curve may assume many sorts of shapes. An example is given in *fig. 2*. The transverse luminous intensity $I_{0,\alpha}$ in the direction α is in this case represented by the product nI_0, where I_0 is the transversal luminous intensity of one lamp without fixture.

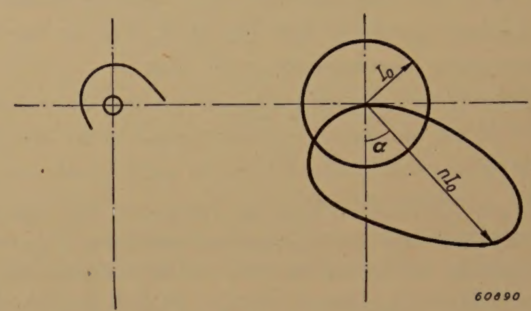


Fig. 2. On the right, distribution curve of the transverse luminous intensities in the case of a tubular lamp without fixture (circle with radius I_0), and the corresponding curve for an asymmetric fixture represented in cross section on the left.

In the curve representing the factor n of a fixture equipped with several parallel rows of lamps this number of rows is taken into account. The graph therefore contains a circle with radius $n = 1$ applying to one single row of lamps, whereas the vectors of the curve representing the factors n of the fixture relate to the totality of rows concerned.

It goes without saying that the values of the factor n can also be tabulated instead of plotting it in a graph. If the fixture is asymmetrical then on either side of the projection $1'$ $2'$ of the lamp on the horizontal plane in question the variation of n differs. In the case of the example drawn in fig. 2 we find the values:

d/h	3	2	1	0	1	2	3
α	71°30′	63°30′	45°	0°	45°	63°30′	71°30′
n	0	0.4	1.3	1.8	3,1	2.5	1.5

To find the illumination on the work plane for a point in the direction α, the illumination found

[5]) The distribution curve described here is not to be confused with the polar diagram of the light distribution of a point source of light in a meridional plane.

for a lamp without fixture has to be multiplied by the factor n corresponding to that direction.

A numerical example

We shall conclude this article by applying the method described to a simple example.

In a locality where the ceiling and walls are non-reflecting there are two parallel sources of light *I* and *II* mounted along the ceiling. The first source consists of an unbroken series of TL 25 W/33a fluorescent lamps freely suspended, whilst the second source is formed by two short TL 25 W/33a lamps with an asymmetric reflector, the light-distribution curve for which has been drawn in fig. 2.

It is required to determine the illumination along a line *KL* on a horizontal plane *HH* two metres below the light sources. (For the dimensions of the lamps and their position with respect to the line *KL* reference is made to *fig. 3*.)

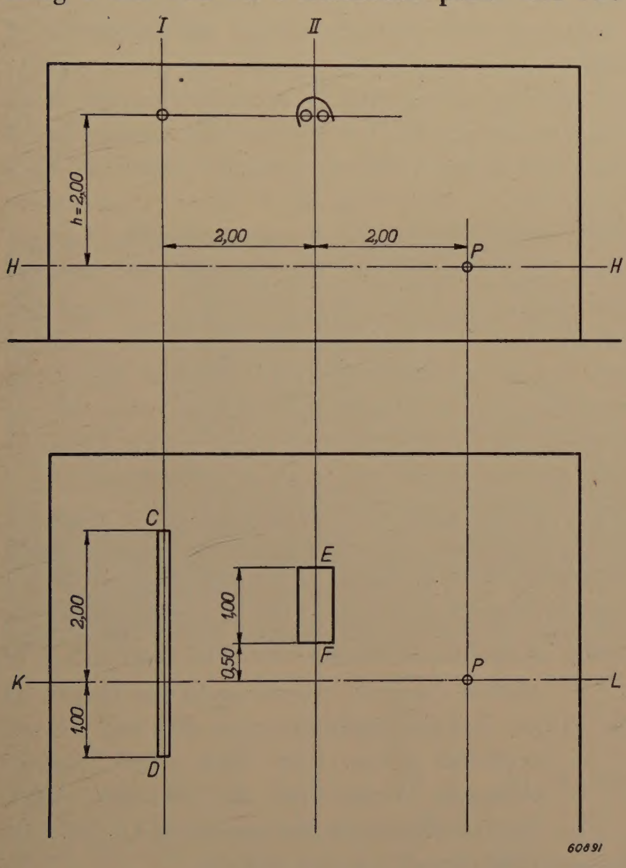


Fig. 3. Positional drawing indicating the dimensions of the two light sources *I* and *II* (referred to in the numerical example dealt with) and also their position with respect to the line *KL* in the work plane *HH*. It was required to calculate the distribution of the illumination along the line *KL*.

For both lamps I_0 = 115 cd/m, so that I_0/h = 57.5 cd/m^2.

To determine the illumination yielded by the lamp *I* we have to take for all points of *KL* in table I $l_C/h = 1$ and $l_D/h = 0.5$, so that for the corresponding f_C and f_D we find:

d/h	3	2	1	0	1	2	3
f_C	0.03	0.08	0.27	0.64	0.27	0.08	0.03
f_D	0.02	0.04	0.16	0.43	0.16	0.04	0.02
f_C+f_D	0.05	0.12	0.43	1.07	0.43	0.12	0.05

In the same way the figures f_E and f_F for the source *II* are found by taking l_E/h = 0.75 and l_F/h = 0.25, thus:

d/h	3	2	1	0	1	2	3
f_E	0.02	0.06	0.23	0.56	0.23	0.06	0.02
f_F	0.01	0.02	0.09	0.24	0.09	0.02	0.01
f_E—f_F	0.01	0.04	0.14	0.32	0.14	0.04	0.01
n	0	0.4	1.3	1.8	3.1	2.5	1.5

The factors f_E—f_F then have to be multiplied by the coefficient n corresponding to each value of d/h.

The illumination in any point is then found by adding up the illuminations yielded by the light sources *I* and *II*. Let us take as example the point *P* (fig. 3) on the line *KL*. There the illumination amounts to

$$(0.12 + 3.1 \times 0.14) \times 57.5 = 32 \text{ lux.}$$

Summary. A simple method is discussed enabling one to calculate the illumination obtained in a certain point from linear sources of light. The calculation is restricted to the distribution of the illumination in a horizontal plane derived from direct lighting by means of one or more linear sources of light situated in a higher horizontal plane, for instance along the ceiling. The results of the calculations are compiled in a table. It is also explained how account can be taken of a fixture. Finally the theory is applied to a numerical example.

ABSTRACTS OF RECENT SCIENTIFIC PUBLICATIONS OF THE N.V. PHILIPS' GLOEILAMPENFABRIEKEN

Reprints of these papers not marked with an asterisk can be obtained free of charge upon application to the address on the back cover.

1899: G. Diemer and J. L. H. Jonker: Low-distortion power valves (Wireless Engr. **26**, 385-390, Dec. 1949).

A survey is given of various low-distortion valve constructions. Two new constructions are described by means of which the second harmonic of a single-stage pentode amplifier can be considerably reduced, resulting in a reduction of the total distortion by a factor of 2 up to an output of about 25% of the static anode dissipation. For even larger outputs (up to 50% of the static anode dissipation) the distortion is the same as that of a normal valve. The new valves have an I_a-V_a characteristic that is practically linear in the neighbourhood of the normal working point.

1900: L. A. Ae. Sluyterman and H. J. Veenendaal: A method for the detection of amphoteric substances in paper chromatography (Rec. Trav. Chim. Pays-Bas **68**, 717-720, 1949, No. 9/10).

Paper chromatograms are treated with a solution of tropaeolin OO, dried and held in hydrochloric acid vapour. Amphoteric substances appear as yellow spots on a red background.

1901: M. Asscher: A new synthesis of ω-amino-p-hydroxyacetophenones and their reduction to the corresponding amino-aethanols (Rec. Trav. Chim. Pays-Bas **68**, 960-968, 1949, No. 11).

A new synthesis is described of compounds of the type

$$HO - \langle\overline{}\rangle - CO \,.\, CH_2N <$$

by the condensation of phenol or its derivatives with aminoacetonitriles according to the method of Hoesch and Houben. The corresponding alcohols are prepared by catalytic reduction of the ketones obtained.

1902: F. A. Kröger, J. E. Hellingman and N. W. Smit: The fluorescence of zinc sulphide activated with copper (Physica The Hague **15**, 990-1018, 1949, No. 11/12).

The fluorescence of zinc sulphide activated with copper consists of three bands: a green band and a blue band caused by copper, and the blue band of self-activated zinc sulphide. In addition to fluorescence centres copper may also give rise to quencher centres. The fluorescence centres have an absorption band associated with them, situated at the long-wave end of the fundamental absorption of zinc sulphide.

The variation in the relative concentration of the various centres with the conditions of preparation has been studied, using controlled atmospheres of H_2S-HCl, H_2-HCl, etc. At high temperatures ($T > 1050$ °C) high HCl contents in the atmosphere enhance the formation of green centres while low HCl contents favour the formation of blue copper centres, but neither of these centres are formed when HCl is entirely lacking. High concentrations of H_2S favour the formation of quencher centres. When products made at high temperatures are fired at a lower temperature (e.g. 400 °C), reducing atmospheres like H_2, N_2 (and also O_2!) enhance the blue centers and destroy quencher centres, while oxidizing atmospheres (H_2S, HCl) have the opposite effect. These effects can be explained if it is assumed that the green copper centre is formed by CuCl, the blue copper centre by CuCl-Cu, the blue zinc centre by ZnCl and the quencher centre by Cu_2S, all being incorporated in the zinc sulphide lattice. The physical behaviour of the system is discussed on the basis of the Schön-Klasens theory of energy transfer between centres.

1903: C. J. Bouwkamp: On the evaluation of certain integrals occurring in the theory of the freely vibrating circular disk and related problems (Proc. Kon. Ned. Akad. Wetenschappen Amsterdam **52**, 987-994, 1949, No. 9; Indigationes Mathematicae **11**, 366-372, 1949, fax. 5).

In the theory of the acoustic radiation by a freely vibrating rigid circular disc integrals of the form

$$\int_0^1 P_{2n+1}(\sqrt{1-\varrho'^2})\varrho' d\varrho' \int_0^{2\pi} [\varrho^2 - 2\varrho\varrho' \cos\vartheta' + \varrho'^2]^{1/2(m-1)} d\vartheta'$$

occur in which P is a Legendre polynomial. The same integrals occur in the theory of acoustic diffraction by a circular disc or by a circular aperture. It appears that these integrals are polynominals in ϱ^2. These may be written either in the form of a hypergeometric series or as a linear combination of Legendre polynomials.